The relative position priming effect depends on whether letters are vowels or consonants

Jon Andoni Duñabeitia[1] and Manuel Carreiras[1,2,3]

[1] Basque Center on Cognition, Brain and Language (BCBL); Donostia, Spain

[2] IKERBASQUE, Basque Foundation for Science; Bilbao, Spain

[3] University of the Basque Country; Bilbao, Spain

Address for correspondence:

Jon Andoni Duñabeitia

Basque Center on Cognition, Brain and Language

Paseo Mikeletegi, 69

20009 Donostia (Spain)

phone: +34 943309300

email: j.dunabeitia@bcbl.eu

Abstract

The relative position priming effect is a type of subset priming in which target word recognition is facilitated as a consequence of priming the word with some of its letters, maintaining their relative position (e.g., *csn* as a prime for *casino*). Five experiments were conducted to test if vowel-only and consonant-only subset primes contribute equally to this effect. Experiment 1 revealed that this subset priming effect emerged when primes were composed exclusively of consonants, as compared to vowel-only primes (*csn-casino* vs. *aia-animal*). Experiment 2 tested the impact of letter frequency in this asymmetry. Subset priming effects were obtained for both high and low frequency consonants, but not for vowels, which rules out a letter frequency explanation. Experiment 3 tested the role of phonology and its contribution to the priming effects observed, by decreasing the prime duration. The results showed virtually the same effects as in the previous experiments. Finally, Experiments 4 and 5 explored the influence of repeated letters in the primes on the magnitude of the priming effects obtained for consonant and vowel subset primes (*iuo-dibujo* and *aea-madera* vs. *mgn-imagen* and *rtr-frutero*). Again, the results confirmed the priming asymmetry. We propose that a functional distinction between consonants and vowels, mainly based on the lexical constraints imposed by each of these types of letters, might provide an explanation for the whole set of results.

The relative position priming effect depends on whether letters are vowels or consonants

Classic models of visual word processing and orthographic encoding such as the interactive-activation model (McClelland & Rumelhart, 1981) and its variants assert that the spatial location of each letter within a string is perfectly coded (i.e., a “channel specific” coding scheme). However, these and other channel-specific coding schemes (Coltheart, Rastle, Perry, Ziegler, & Langdon, 2001; Grainger & Jacobs, 1996; Rumelhart & McClelland, 1982) fail to account for two key effects: the transposed-letter priming effect and the relative position priming effect (Grainger, 2008, for a comprehensive review).

The transposed-letter priming effect refers to the fact that nonword primes created by transposing two letters from a real word produce form-priming effects, relative to the appropriate orthographic control (e.g., *jugde-JUDGE* vs. *jupte-JUDGE*; Perea & Lupker, 2003; see also Christianson, Johnson, & Rayner, 2005; Duñabeitia, Molinaro, Laka, Estévez & Carreiras, 2009; Duñabeitia, Perea, & Carreiras, 2007; Forster, Davis, Schoknecht, & Carter, 1987; Perea & Carreiras, 2006a, 2006b, 2006c; Perea & Carreiras, 2008; Schoonbaert & Grainger, 2004). The relative position priming effect is a type of subset letter priming, defined as a “*variety of orthographic priming that involves a change in length across prime and target such that shared letters can have the same order without being matched in terms of absolute, length-dependent position*” (Grainger, 2008, p. 16). More specifically, in different versions of the priming paradigm it has been shown that primes composed of a subset of the target word’s letters that preserves their relative position but not their absolute position facilitate target word recognition, as compared to a control condition. In other words, primes composed of a subset of the target word's letters that preserves their relative ordering within the string (e.g., *CSN* from *CASINO*) speed up the recognition of the target word, as compared to an unrelated priming condition (e.g., *MVR*). Furthermore, when primes are composed of a subset of the target word's letters that preserves their absolute position (e.g., *C-S-N-*), the observed priming effects are not distinguishable from the priming effects for the relative position priming condition (see Van Assche & Grainger, 2006, for review).

Humphreys, Evett and Quinlan (1990) were the first to examine this issue with a four-field masking procedure. In their study, participants had to recognize a masked target word (in uppercase), which was briefly preceded by a masked prime (in lowercase). In the four-field masking paradigm, a trial consists of the sequence mask-prime-target-mask. The exposure durations of the four fields (the two masks and the prime-target strings) are adjusted so that participants correctly report a certain amount of the targets (about 40% in their case). Humphreys et al. showed that two strings that differ in length and therefore in the absolute position of the letters, but that do not differ in the relative order/position of the letters produce significant facilitation effects as compared to an unrelated condition. Peressotti and Grainger (1999), in a subsequent lexical decision study, explored the relative position priming effect presenting participants with French words like *BALCON* (the French for *balcony*), that could be briefly preceded by strings that kept or altered the relative and absolute positions of the letters. Even though the effect is termed "the relative position priming effect", it should be considered that manipulations within this paradigm consist of a subset of the letters of the target vs. a different set of letters. Hence, this effect is a form of partial or subset priming, and consequently also focuses on letter identity assignment processes, not only on letter position assignment processes. For the sake of simplicity, we will use the terms "subset priming" and "relative position priming" as interchangeable in this manuscript. In their Experiments 3A and 3B, Peressotti and Grainger showed that relative position primes (e.g., *BLCN*) facilitated the recognition of the target word as compared to a control condition in which the letters were completely unrelated to the target (e.g., *FTRM*). Furthermore, these authors also showed that changing the relative position order (e.g., *NCLB* or *BCLN*) never led to significant facilitation with regard to the control condition. More importantly, they found a priming effect of the same magnitude when the prime string was formed by nonword primes created by replacing some letters with hyphen marks (e.g., *B-LC-N*; the absolute position condition) as compared to when the prime string was formed by the same letters without the hyphens (e.g., *BLCN*; the relative position condition).

In a recent paper by Grainger, Granier, Farioli, Van Assche, and van Heuven (2006) the authors extended the results from the Peressotti and Grainger (1999) study in several different ways. On the one hand, Grainger et al. replicated the relative position priming effect under classical masked priming conditions in a series of lexical decision experiments, with fixed prime exposure duration. On the other hand, these authors tested relative and absolute position priming effects and compared them to a control condition made of unrelated real letters (that could be of the same relative position length or of the same absolute position length; see Experiments 1a and 1b). Interestingly, a similar pattern of results has recently been obtained in an electrophysiological study testing target word activation by relative position primes and absolute position primes while participants' event-related brain potentials were recorded. Grainger and Holcomb (2009), in a semantic categorization go/no-go task, showed that target word processing was benefitted by both types of primes (i.e., relative and absolute-position primes), as compared to the corresponding unrelated priming conditions. These effects were mainly evident in the N400 component (in a time window between 375 and 550 ms after target stimulus onset). Similar effects in the N400 component, but also in an earlier time-window (associated with the N250 component) were obtained by Carreiras, Duñabeitia and Molinaro (2009).

Grainger et al. (2006) discussed the so-called relative position priming effect in terms of standard models as well as the recently-proposed orthographic encoding models. As mentioned before, none of the standard models can account for this type of subset priming, since they assume position-specific coding schemes. In contrast, the presence of relative position priming effects is a natural consequence of the input coding scheme in the SOLAR model (Davis, 2010), and the open-bigram models (SERIOL model, Whitney, 2001; discrete open-bigram model, Grainger & van Heuven, 2003; see also the LCD model, Dehaene, Cohen, Sigman & Vinckier, 2005). Davis' SOLAR model readily captures the data pattern that has been previously reported for masked subset primes (such as relative position primes), as shown in a number of simulations (see Davis, 2010, simulations 17, 18 and 20). Grainger et al. (2006) proposed that open-bigram models are especially suited to account for this effect. The common underlying idea is that (open) bigrams are formed across adjacent and non-adjacent letters, always in the correct order. Thus, a word like *BALCON* would activate the following bigrams: *BA*, *BL*, *BC*, *BO*, *BN*, *AL*, *AC*, *AO*, *AN*, *LC*, *LO*, *LN*, *CO*, *CN* and *ON*. The relative position prime *BLCN* would activate six of these bigrams: *BL*, *BC*, *BN*, *LC*, *LN* and *CN*. These coded bigrams would send activation to the level of whole-word orthographic representations via bidirectional excitatory connections, and the word form *BALCON* would become active. In a further development, Grainger proposed the overlap open-bigram model, accounting for the activation of noncontiguous bigrams too (e.g., Perea, Duñabeitia & Carreiras, 2008). This open-bigram model assumes that the degree of activation of open bigrams is different as a function of the distance between the two letters. Thus, in the previous example (i.e., *BALCON*), the contiguous bigram *BA* would generate higher activation than the noncontiguous bigram *BL*, which in turn would generate higher activation than the bigram *BC*.

In spite of this apparent suitability of open-bigram models to account for subset priming effects, there is an issue that has not been covered by these models and that has been unattended to in almost all preceding studies on the so-called relative position priming effect: the vowel-consonant differentiation. In the Peressotti and Grainger (1999) study, the manipulation was carried out maintaining most of the consonants between prime and target strings. This implies that the letters deleted in order to create subset primes were vowels in most of the cases (e.g., deleting *A* and *O* from *BALCON* to obtain the relative position prime *BLCN*). This was not the case in the Grainger et al. (2006) study, since they also included vowels in the subset primes, although to a lesser degree than consonants. As they did not control for vowels and consonants, they carried out a *post hoc* correlation analysis in order to seek for a possible influence of this factor in their priming effects. The correlation between their priming effects and the proportion of vowels in the primes was not significant (r=-0.02). However, they stated that their results pointed to weaker priming as the proportion of vowels increased. Obviously, this is not a trivial issue since the pattern of subset priming effects might be asymmetric when letter type (vowel/consonant) is taken into account, as has been previously shown for other types of orthographic priming effects, such as the transposed-letter priming effect (see Perea & Lupker, 2004). This potential outcome would be of high relevance for orthographic encoding models that *a priori* do not differentiate between consonants and vowels. Moreover, such a result could shed some light on the relative contribution of vowels and consonants to visual word recognition and lexical access. In fact, in recognition of the importance of this issue, Grainger et al. stated that "*a direct manipulation of the proportion of consonants and vowels shared by prime and target is necessary to clarify the role of this factor in relative-position priming*" (p. 871). The goal of the present study is to shed light on this topic with a direct manipulation of the types of letters used in the so-called relative position priming (vowels and consonants).

Recent evidence obtained using different methodologies (e.g., behavioral, ERPs, fMRI) as well as neuropsychological data has revealed important differences between vowel and consonant processing (Caramazza et al., 2000; Carreiras & Price, 2008; Carreiras, Vergara, & Perea, 2007, 2009; Cotelli et al., 2003; Cubelli, 1991; Ferreres et al., 2003; Miceli et al., 2004; Nazzi & New, 2007; Tainturier & Rapp, 2004). For instance, Perea and Lupker (2004) reported a study using the transposed-letter paradigm in which participants were presented with words briefly preceded by nonword primes that included consonant transpositions or replacements (*caniso* and *caviro*, from *casino*), or by nonword primes that included vowel transpositions or replacements (*anamil* and *anemol*, from *animal*). The results showed a difference in the priming effects between the transposed versus the replaced-letter priming conditions as a function of letter type. The authors found a significant interaction showing that the transposed-letter priming effect was only significant when the letter transposition involved two consonants. Furthermore, in a single presentation lexical decision experiment (Experiment 4), Perea and Lupker showed that participants classified transposed-consonant nonwords (*tradegia,* derived from the Spanish word *tragedia*) as nonwords less accurately than transposed-vowel nonwords (*absuloto,* derived from the Spanish word *absoluto*; see also Lupker, Perea, & Davis, 2008). These results, together with those from related psycholinguistic studies (e.g., Carreiras, Gillon-

Dowens,Vergara & Perea, 2009; Lee, Rayner, & Pollatsek, 2001), suggest that there is a clear distinction between the contributions of vowels and consonants in word reading.

In a similar vein, Carreiras, Duñabeitia and Molinaro (2009) recently investigated whether the consonant-vowel differentiation would also hold in an ERP masked priming experiment exploring subset priming effects. Carreiras et al. presented participants with target words that could be preceded by primes made of a subset of the targets' letters holding their relative position with respect to the targets, by primes that were identical to the targets, or by unrelated primes. Critically, half of the subset primes were exclusively made up of consonants (e.g., *frl – farol* [*lantern*]), while the other half were composed only of vowels (e.g., *aeo – acero* [*steel*]). Carreiras et al. found significant differences in two components: the N250 and the N400. In these two components, larger negativities were found for target words preceded by control primes as compared to target words preceded by identity and consonant subset primes, which in turn did not significantly differ from each other. In contrast, vowel subset primes and unrelated control primes did not differ from each other, and both elicited larger negativities as compared to identical primes. Hence, Carreiras et al. found a clear dissociation between the priming effects observed for consonant and vowel subset (relative position) primes. The authors explained this difference in terms of the different lexical activation patterns elicited by vowel and consonant subset primes, under the assumption that consonant primes are much more lexically constraining than vowel primes (see Nespor, Peña, & Mehler, 2003, for discussion).

Why should consonant subset primes and vowel subset primes elicit different patterns of target word activation? It has been repeatedly proposed that the functional linguistic role of each of these letter types (consonants and vowels) is radically different, with the main role of consonants related to lexical access by constraining the lexicon, whereas the main role of vowels is to allow identification of properties of the syntactic structure and the rhythmic class (see Nespor et al., 2003; see also Bonatti, Peña, Nespor, & Mehler, 2005; Mehler, Peña, Nespor, & Bonatti, 2006; Pons & Toro, 2010; Toro, Nespor, Mehler, & Bonatti, 2008). Except for a very few cases (e.g., Swedish), consonants are cross-linguistically more numerous than vowels, and therefore certain consonant combinations are by default less frequent than certain vowel combinations. Hence, it is relatively straightforward to assume that consonants, as compared to vowels, will impose a higher lexical constraint. According to this differentiated distribution of vowels and consonants in most languages, letter combinations will radically vary in terms of the number of lexical candidates they can activate (i.e., the number of words that contain those letter combinations) as a function of the number of consonants or vowels they include. While vowel combinations will not be lexically highly constraining, since the same vowel pattern might be contained in many words due to the scarce number of vowels, consonant combinations will significantly reduce the amount of potential lexical candidates, facilitating the process of lexical selection. In the following, we will refer to this property derived from the combinatorial probabilities of the consonants and the vowels as *the Lexical Constraint Hypothesis*. Given the higher number of consonants than vowels, and therefore given the higher restriction imposed in the lexicon by the combination of consonants as compared to the combination of vowels, it is predicted by the Lexical Constraint Hypothesis that readers will strongly rely on the information contained in the consonant skeleton of a word, which would be of crucial help in selecting the target string among a number of lexical competitors. In other words, if we assume that according to purely combinatorial regularities consonant permutations are much more lexically restricting than vowel permutations, it could be expected that subset primes consisting of only consonants will show greater priming effects than subset primes consisting of only vowels, since consonant primes will elicit a lesser degree of dispersion of lexical activation than vowel primes.

The Lexical Constraint Hypothesis seems a valid explanation to account for the processing differences for primes consisting only of vowels as compared to primes consisting only of consonants, as shown by Carreiras et al. (2009). However, before drawing strong conclusions with regard to this hypothesis, a replication of Carreiras et al.'s findings would be beneficial. Moreover, in the study by Carreiras et al. participants were asked to passively read the critical trials, and no overt response was required from them (i.e., the critical trials were no-go trials in a go/no-go semantic categorization task; see also Grainger & Holcomb, 2009, for a similar procedure), so to our knowledge there is no empirical behavioral support for their conclusion. The present study aims to replicate and extend those findings in a series of masked subset priming lexical decision experiments. In addition, we will investigate whether letter frequency, phonology and the repetition of letters can account for this asymmetry between consonants and vowels.

The assumption of different lexical activation patterns for consonants and vowels has a clear impact for the recently-proposed letter coding schemes, because none of the new computational models make any *a priori* distinction between consonants and vowels, as stated by Perea and Lupker (2004). One feasible solution to this problem is to consider that these differences emerge as a consequence of a letter frequency effect. As mentioned above, in many languages there are more consonants than vowels, and consequently vowels are much more frequent than consonants. Letter frequency effects could be easily accommodated by computational models, without making any basic distinction between consonants and vowels. Therefore, it is very important to investigate whether the differences observed between consonants and vowels in the transposed letter effect hold for the subset priming effect, and whether such differences, if they exist, can be accounted for simply by letter frequency or whether they are due to other differences between consonants and vowels (e.g., the different lexical constraints imposed by these two entities). The present work is aimed at shedding some light on this issue.

In Experiment 1 we tested different types of subset priming effects (relative and absolute position priming) for vowels and for consonants. If consonant identities are more informative than vowel identities, as predicted by the Lexical Constraint Hypothesis, then larger subset priming effects should be found for relative position primes like *nml-animal* than for those like *aio-casino*, thus replicating the electrophysiological pattern observed by Carreiras et al. (2009). A second aim of this work is to examine the frequency account by testing consonants of different frequencies in Experiment 2. If the difference between consonants and vowels does not rely simply on frequency, consonants of high and low frequency should yield a similar pattern of results, and both should yield a different pattern of results from that of vowels. Lupker, Perea and Davis (2008) proposed that instead of a categorical consonant-vowel difference, the higher transposed-letter effects found when consonants were involved as compared to vowels mostly reflected the frequencies of the letters manipulated. They tested this hypothesis in a masked priming experiment where real words could be briefly preceded by nonwords created by transposing or replacing two high-frequency consonants (e.g., *PRETEXT*) or two low-frequency consonants (e.g., *SIZABLE*). They found the typical transposed-letter priming effect, with words preceded by a transposed-letter nonword responded to faster than words preceded by a replaced-letter nonword (Duñabeitia, Perea & Carreiras, 2007; Perea, Duñabeitia & Carreiras, 2008; Perea & Lupker, 2003; Schoonbaert & Grainger, 2004). More importantly, they found an interaction that showed that the transposed-letter priming effect was only significant for the low-frequency consonants (e.g., *sibazle-SIZABLE*; a 34 ms effect) and not for the high-frequency consonants (e.g., *pterext-PRETEXT*; a 11 ms difference; see also Duñabeitia, Gutiérrez, & Mena, 2006). As a consequence of these results, they stated that "frequency matters in a way that could explain at least part of the transposed-letter prime advantage for C-C primes over V-V primes". They accompanied this with the proposal that the position of low-frequency letters is coded in a "loose" fashion as a result of the difference in the size of the populations of neurons involved in their codification: frequent letters are coded by a larger population of neurons than less frequent letters. Hence, these results offer a new possibility of understanding previous findings in terms of letter frequency.

As we stated above, none of the recently proposed coding schemes accounts for a consonant-vowel difference. Clearly, a frequency-based explanation is easier to implement in these models, simply integrating frequency as a factor, or assuming that frequent letters involve less noise for the system than infrequent letters. This would result in a "loose" position codification of "noisy" letters (low-frequency letters), and in a more precise position encoding of less "noisy" letters (high-frequency letters), therefore accounting for the transposed-letter effects that have been previously reported. If this frequency explanation is valid also at the level of subset priming, different relative position priming effects should be expected for high-frequency consonants and for low-frequency consonants.

Experiment 1

In Experiment 1 we investigated potential differences in the relative and absolute position priming effects between subset strings that share with targets only the consonants (e.g., *f-r-l* and *frl* priming *farol*, the Spanish for *bluff* and *lantern*), or that share only the vowels (e.g., *a-e-o* and *aeo* priming *acero*, the Spanish for *steel*). Following the design in Grainger et al.'s (2006) Experiment 1a, we also included a disrupted absolute position condition (e.g., *fr--l* and *ae--o*). Primes in the absolute position and the disrupted absolute position conditions have the same length as target stimuli, and in both cases the relative position letter information is identical, even though the exact position with respect to the target is altered in the disrupted absolute position priming condition. Thus, finding equivalent priming effects for the three subset conditions (absolute position, relative position and disrupted absolute position) would imply that letters are encoded in a relative position rather than in an absolute position (note that the only common aspect of the three conditions is that the relative position information is equivalent). In fact, Grainger et al. (2006) obtained similar significant priming effects for the relative, absolute and disrupted absolute position conditions as compared to an unrelated condition (e.g., *tsb* and *iui*), that was also included in the present experiment.

Method

Participants. Forty-four undergraduate students from the participant databases of the Basque Center on Cognition, Brain and Language and from the University of La Laguna took part in this experiment in exchange for course credit. All of them were native Spanish speakers and had normal or corrected-to-normal vision.

Materials. A total of 120 words were selected from the Spanish LEXESP database (Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000) and analyzed with the B-PAL software (Davis & Perea, 2005). All of the words were five letters long (see Appendix). Half of these words included a vowel as initial, middle and final letters (e.g., *acero*, the Spanish for *steel*). The mean frequency of these words was 11.44 appearances per million (range: 0.18-100.36), and the mean number of orthographic neighbors was 3.34 (range: 0-10). The other half was composed of words that included a consonant as initial, middle and final letters (e.g., *farol*, the Spanish for *lantern*). These words were matched to the previous ones in frequency (mean: 13.78; range: 0.18-99.29) and number of orthographic neighbors (mean: 3.40; range: 0-12) in a pairwise manner using the Match software (van Casteren & Davis, 2007). These words could be preceded 1) by the initial, middle and final letters (relative position; e.g., *aeo* - *acero* and *frl* - *farol*), 2) by the initial, middle and final letters separated by hyphens (absolute position; e.g., *a-e-o* - *acero* and *f-r-l* - *farol*), 3) by the initial, middle and final letters with inserted hyphen marks disrupting the absolute position information (disrupted absolute position; e.g., *ae--o* - *acero* and *fr--l* - *farol*), or 4) by three consonants or vowels that did not appear in the target word (control; e.g., *iui* - *acero* and *tsb* - *farol*). In order to make lexical decision possible, 120 nonwords were created. These nonwords kept the same consonant/vowel structure as the real words, and were created by replacing the consonants from the vowel word subset (e.g., *apevo* from *acero*), or by replacing the vowels from the consonant word subset (e.g., *furel* from *farol*). (Note that the same criteria for nonword creation were followed in all the experiments reported in this study). The same four priming conditions as for the words were used for the nonwords. Four lists of materials were created, so that each target appeared once in each, but each time in a different priming condition. Eleven participants were assigned to each of the lists.

Procedure. Participants were individually tested in a well-lit soundproof room. The presentation of the stimuli and recording of the responses was carried out using DMDX software (Forster & Forster, 2003) on a PC with a CRT monitor. Each trial consisted in the presentation of a forward mask created by hash mark symbols in the center of the screen for 500 ms, followed by the displaying of the prime for 50 ms, and immediately followed by the presentation of the target. Primes and targets were presented in lowercase, and were also presented centered. Primes were presented in 10 pt. Courier New font and targets in 12 pt. Courier New font, in order to minimize physical overlap. Primes and targets were presented in lowercase following previous work on the relative position priming effect (e.g., Grainger et al., 2006; Peressotti & Grainger, 1999; Van Assche & Grainger, 2006) in which primes and targets were also presented in the same case. Target items remained on the screen for 2500 ms or until a response was given. Participants were instructed to press ‘M’ on the keyboard when the displayed item was a real Spanish word and ‘Z’ when it was not. They were told to do so as fast and as accurately as possible. 12 practice trials (6 words and 6 nonwords) were used for warm-up purposes. All the items were randomly presented in order to avoid order repetition effects across participants. The experiment lasted for around 10 minutes.

Results

All reaction times below 250 ms or above 1500 ms and all reaction times associated with incorrect responses were not included in the latency analyses. Response times and error rates associated to each experimental condition are displayed in Table 1. Two analyses were carried out. First, a full ANOVA was performed following a 4 (Type of relationship: Relative position, Absolute position, Disrupted absolute position, Unrelated) x 2 (Type of letter: Consonants, Vowels) x 4 (Lists: List 1, List 2, List 3, List 4) design. Second, ANOVAs for the pairwise comparisons with the control prime condition were performed in order to examine priming effects in the various related prime conditions, considering Type of letter (Vowels, Consonants), Relatedness (Related, Unrelated) and List (List 1, List 2, List 3, List 4) as factors. The factor List was included as a dummy variable (Pollatsek & Well, 1995).

--- Insert Table 1 here ---

Word data.

The full ANOVA on the latency data showed a main effect of Type of letter, that was only significant in the analysis by participants, F1(1,40)=7.97, p<.01; F2(1,112)=2.56, p>.10. The effect of Type of relationship approached significance in the analysis by participants, F1(3,120)=3.62, p<.02; F2(3,336)=1.75, p>.15. The interaction between the two factors was significant, F1(3,120)=6.25, p<.01; F2(3,336)=4.00, p<.01.

None of the effects or interactions on the full ANOVA performed on the error rates was significant.

Relative position. Words preceded by related primes were recognized faster than words preceded by unrelated primes, although this difference was not significant in the analysis by items, F1(1,40)=9,87, p<.01; F2(1,112)=2.38, p>.12. The effect of Type of letter (consonant or vowel) was not significant, both ps>.35. Importantly, there was a significant interaction between Type of letter and Relatedness, F1(1,40)=18.35, p<.01;

F2(1,112)=8.74, p<.01. Simple tests showed that there was a significant relative position priming effect (a 31 ms effect) for words preceded by consonants, F1(1,40)=26.32, p<.01; F2(1,56)=11.93, p<.01. On the contrary, words preceded by vowels did not show any significant relative position priming effect (a negligible -4 ms effect), both Fs<1 and ps>.35. None of the effects or interactions on the error rates were significant.

Absolute position. There was a main significant effect of Relatedness in the analysis by participants, showing that words preceded by related primes were recognized faster than words preceded by unrelated primes, F1(1,40)=9.65, p<.01; F2(1,112)=4.29, p<.05. The main effect of Type of letter was not significant, Fs<1 and ps>.40. The interaction between the two factors was significant, F1(1,40)=9.00, p<.01; F2(1,112)=6.80, p<.02. Simple tests showed that for the consonant group there was a significant effect of absolute position priming (33 ms), F1(1,40)=18.73, p<.01; F2(1,56)=10.99, p<.01. In contrast, there was no such effect for the vowel group (a non-significant 1 ms difference), both Fs<1 and ps>.70. None of the effects or interactions on the error rates was significant.

Disrupted absolute position. The main effect of Relatedness was significant in the analysis by participants, F1(1,40)=5.04, p<.04; F2(1,112)=.83, p>.35. The effect of Type of letter did not reach significance, both ps>.15. The interaction between the two factors was significant, F1(1,40)=12.56, p<.01; F2(1,112)=7.88, p<.01. Simple tests showed that there was a 31 ms advantage for words in the consonant group preceded by related primes, F1(1,40)=21.63, p<.01; F2(1,56)=8.19, p<.01. Words in the vowel group were responded to similarly (a negligible -7 ms difference) in the two priming conditions, both ps>.20. None of the effects or interactions on the error rates was significant.

Nonword data.

None of the ANOVAs revealed any significant effect for the latency data or the accuracy data, except for a main effect of Type of letter in the latency data, F1(3,120)=139.59, p<.01; F2(1,112)=69.65, p<.01, and in the error data, F1(3,120)=22.57, p<.01; F2(1,112)=8.32, p<.01, showing that nonwords in the vowel subset were recognized faster and more accurately than nonwords in the consonant subset.

The results from this experiment revealed that absolute position, relative position and disrupted absolute position priming effects can be successfully obtained when the letters shared between prime and target are consonants (31, 33 and 31 ms respectively). Similar to the results in Peressotti and Grainger (1999) and Grainger et al. (2006), we found no differences between the three conditions, revealing that the relative position priming effect is as effective as the absolute position priming effect. Importantly, these effects vanish when the shared letters are vowels instead of consonants. We believe that the present results point to a clear dissociation between consonant and vowel subset priming effects. These results seem to confirm the prediction derived from the Lexical Constraint Hypothesis, which states that primes consisting only of consonants would be highly lexically indicative or meaningful (due to the number of lexical candidates they activate), while primes consisting of only vowels would be less lexically informative. However, before drawing conclusions about the limits of the relative position priming effects, we need to rule out one possibility that was offered by Lupker, Perea and Davis (2008). Lupker et al. showed that the transposed-letter similarity effect was more robust for low-frequency consonants than for high-frequency consonants, and that it disappeared for vowel transpositions (also Duñabeitia et al., 2006). In Experiment 2 we explore if letter frequency and not the different lexical constraints imposed by consonants and vowels is the factor responsible for the null effect for vowel relative position priming. To this end, in Experiment 2 participants were presented with targets including low-frequency consonants, high-frequency consonants or vowels, preceded by primes formed by letters in their absolute position or in their relative position. The disrupted absolute position priming condition from Experiment 1 was not included in Experiment 2, in order to maximize the number of items in the critical conditions. In addition, it should be noted that in Experiment 1 all the words from the vowel group were tri-syllabic (e.g., *acero*, syllabified as *a.ce.ro*), while all the words from the consonant group were bi-syllabic (e.g., *farol*, syllabified as *fa.rol*). It is possible that this difference between the two sets of words might have had an impact on the results observed, since the relative position priming effect was only present in the consonant (namely the bi-syllabic) group of words. In Experiment 2 we overcame this potential limitation by using words that were in all cases tri-syllabic (e.g., *medida*, *cocina* and *animal*, syllabified as *me.di.da*, *co.ci.na* and *a.ni.mal*, respectively).

Experiment 2

Method

Participants. Forty-two undergraduate students from the University of La Laguna and from the University of the Basque Country took part in this data collection. None of them had taken part in Experiment 1.

Materials. A total of 144 tri-syllabic six-letter words were selected from the Spanish database. 48 of these words had a low frequency consonant in first, third and fifth position (low frequent consonant condition; e.g., *medida*, the Spanish for *measure*). The letters that were chosen were [b,d,j,m,v,z,g,f,p]. These letters altogether summed 17.16% of the letter appearances in Spanish, showing that they are low frequency letters (mean frequency in percentage of appearances: 1.91%). The other group of 48 words had a high frequency consonant in first, third and fifth position (high frequency consonant condition; e.g., *cocina*, the Spanish for *kitchen*). The letters involved in this group were [t,n,c,r,s,l] and summed 35.68% of the letter appearances in Spanish, being high-frequency letters (mean frequency in percentage of appearances: 5.95%). The third group of 48 words was composed by words with vowels in first, third and fifth position (vowel condition; e.g., *animal*, the Spanish for animal). The Spanish vowels accounted for 45.63% of the letter-frequency distribution (mean frequency in percentage of appearances: 9.13%). The three groups of words were matched as closely as possible in lexical frequency (low frequency consonant: 10.97; high frequency consonant: 9.40; vowel: 9.64) and in number of orthographic neighbors (low frequency consonant: 2.5; high frequency consonant: 2.3; vowel: 1.5) [Footnote 1]. All these 144 words were used as targets, and could be preceded 1) by their first, third and fifth letters (relative position; e.g., *mdd* - *medida*, *ccn* - *cocina*, *aia* - *animal*), 2) by their first, third and fifth letters followed by hyphens (absolute position; e.g., *m-d-d-* - *medida*, *c-c-n-* - *cocina*, *a-i-a-* - *animal*), or 3) by three different letters of the same frequency range (control; e.g., *vbb* - *medida*, *rrs* - *cocina*, *eoe* - *animal*). Relative position primes in the low frequency consonant set had a mean letter frequency of 2.61 (standard deviation: 0.73). Relative position primes in the high frequency consonant set had a mean letter frequency of 6.03 (standard deviation: 0.73). Finally, relative position primes in the vowel set had a mean letter frequency of 11.70 (standard deviation: 2.08). T-tests showed that the three frequency groups differed significantly from each other in their average letter frequency (all ps<.001). 144 nonwords were created in order to make lexical decision possible. Three lists of materials were created, so that each target appeared once in each, but each time in a different priming condition. Fourteen participants were assigned to each of the lists.

Procedure. The same procedure as in Experiment 1 was followed. The experiment lasted for around 12 minutes.

Results

All the reaction times below 250 ms or above 1500 ms and all the reaction times associated with incorrect responses were excluded from the latency analyses. Response times and error rates associated to each experimental condition are displayed in Table 2. First a full ANOVA was performed following a 3 (Type of relationship: Relative position, Absolute position, Unrelated) x 3 (Type of letter: Low-frequency consonants, High-frequency consonants, Vowels) x 3 (List: List 1, List 2, List 3) design. Second, ANOVAs for the pairwise comparisons with the control prime condition were performed in order to examine priming effects in the various related prime conditions, considering Type of letter (Low-frequency consonant, High-frequency consonant, Vowel), Relatedness (Related, Unrelated) and List (List 1, List 2, List 3) as a factors.

--- Insert Table 2 here ---

Word data.

The full ANOVA on the latency data showed a main effect of Type of letter which was significant in the analysis by participants, F1(2,78)=8.25, p<.01; F2(2,135)=2.34, p=.10. The main effect of Type of relationship was significant, F1(2,78)=5.59, p<.01; F2(2,270)=6.37, p<.01. The interaction between the two factors was significant, F1(4,156)=4.09, p<.01; F2(4,270)=4.05, p<.01.

The full ANOVA on the error data only showed a main effect of Type of letter, F1(2,78)=20.48, p<.01; F2(2,135)=3.85, p<.03. No other effect or interaction was significant.

Relative position. The analyses showed a main effect of Type of letter, F1(2,78)=11.84, p<.01; F2(2,135)=3.53, p<.04. The Relatedness effect was also significant, with words preceded by related primes being recognized faster than words preceded by unrelated primes, F1(1,78)=12.50, p<.01; F2(1,135)=10.16, p<.01. Importantly, the interaction between the two factors was significant, F1(2,78)=6.85, p<.01; F2(2,135)=5.14, p<.01. Simple tests for each Type of letter group showed that the relative position priming effect was significant for the low-frequency consonant group (26 ms), F1(1,39)=9.15, p<.01; F2(1,45)=8.48, p<.01, and for the high-frequency consonant group (29 ms), F1(1,39)=14.52, p<.01; F2(1,45)=9.12, p<.01. In contrast, the relative position priming effect was not significant for the vowel group (a negligible -6 ms effect), F1(1,39)=1.03, p>.43; F2(1,45)=.79, p>.37. The analyses on the error rates only showed a main effect of Type of letter, F1(2,78)=20.21, p<.01; F2(2,135)=4.12, p<.02.

Absolute position. There was a main effect of Type of letter, F1(2,78)=8.01, p<.01; F2(2,135)=3.08, p<.05, and an effect of Relatedness, F1(1,78)=3.89, p=.06; F2(1,135)=8.33, p<.01. The interaction between the two factors was significant, F1(2,78)=6.28, p<.01; F2(2,135)=7.25, p<.01. Simple tests revealed that words from the low frequency consonant group and words from the high frequency consonant group were recognized faster (20 ms and 26 ms respectively) when preceded by related primes; low frequency consonant: F1(1,39)=4.93, p<.04; F2(1,45)=8.93, p<.01; high frequency consonant: F1(1,39)=7.16, p<.02; F2(1,45)=9.34, p<.01. In contrast, the vowel group showed the opposite trend, with related pairs being recognized more slowly than unrelated pairs (-12 ms), even though this difference was not statistically significant, F1(1,39)=2.68, p>.10; F2(1,45)=2.87, p>.09. The analyses of error rates showed a main effect of Type of letter, F1(2,78)=12.96, p<.01; F2(2,135)=3.24, p<.05.

Nonword data.

The full ANOVA on the latency data only showed a main effect of Type of letter, indicating that nonwords in the vowel set were recognized slower than nonwords in the high frequency set, which in turn were recognized slowed than words in the low frequency set, F1(2,78)=58.65, p<.01; F2(2,135)=14.63, p<.01. This effect was replicated in the ANOVA on the error data, F1(2,78)=19.92, p<.01; F2(2,135)=5.21, p<.01. No other effect or interaction was significant.

The results from Experiment 2 were clear-cut: low and high frequency consonants produced significant relative and absolute position priming effects, whereas vowels did not. Moreover, the magnitude of the priming effects for low and for high frequency consonants was very similar for the relative position (26 and 29 ms) and for the absolute position (20 and 26 ms). Vowels did not produce any signs of relative position subset priming effects (a -3 ms difference). In the case of vowel absolute position primes, the numerical difference pointed in the opposite direction (a -12 ms effect) showing that words preceded by their vowel root in the absolute position were recognized more slowly than words preceded by an unrelated prime. However, considering the lack of significance of those effects, and that this pattern was not so clear in Experiment 1, we will not draw speculative conclusions in this regard. Hence, in the light of these results, the frequency account cannot entirely capture the different priming results that have been obtained for consonants and vowels. Furthermore, the results from Experiment 2 show that the difference in the number of syllables between the consonant and vowel sets used in Experiment 1 does not seem to be responsible for the subset priming asymmetry that was found, since results from this experiment clearly replicated the previous pattern using words that did not differ in the number of syllables. These data suggest that the role of the syllable is very limited in this precise manipulation and its contribution to the subset priming effect is almost null (as has been shown for other manipulations, such as letter transpositions; see Perea & Carreiras, 2006c).

Experiment 3

In the previous experiments, prime strings were presented for 50 ms and it is well-known that phonological co-activation of the prime and target strings might occur within the given stimulus-onset asynchrony (e.g, Ferrand & Grainger, 1993; Grainger, Kiyonaga & Holcomb, 2006; Carreiras, Ferrand, Grainger & Perea, 2005; Pollatsek, Perea & Carreiras, 2005; see Rastle & Brysbaert, 2006, for review). Thus, it could have been the case that phonological (rather than orthographic) effects contributed to the differential priming effects. Previous research on the relative position priming effect has already considered the role of phonology, and its influence has been explored. For instance, in Experiment 6 of the study of Grainger et al. (2006), the role of phonology in the relative position priming effect was tested at two different SOAs: 33 and 83 ms. They predicted that if phonology was somehow responsible for the relative position priming effects, these effects should only be expected at the longer SOA, when phonological priming effects have been previously found. In contrast, if the relative position priming effect is purely orthographic, not phonological, then the effect was expected to emerge at the shorter SOA, when orthographic priming effects tend to appear. Grainger et al. also included a pseudohomophone priming condition (the nonword *silance* as a prime for the French word *silence*), as an established phonological priming effect that shows a target recognition benefit as compared to an orthographic control condition (*silunce* as a prime for *silence*), predicting that this effect should only appear at the longer SOA. Their results revealed a significant relative position priming effect (an overall 20 ms effect) at the shortest SOA (33 ms), but not at the longest SOA (83 ms). In contrast, the pseudohomophone priming effect was only evident at the longest SOA (83 ms), disappearing at the shortest SOA (33 ms). These findings led them to conclude that the relative position priming effect is orthographic in nature.

In spite of the clear effects in their Experiment 6, Grainger et al. (2006) failed to obtain significant masked relative position priming effects at a 33 ms SOA when a pattern mask was included before the presentation of the prime (see Experiment 5). (Note that in their Experiment 6 the pattern mask was not presented before the prime). They stated that the presence or absence of a pattern mask significantly affected the amount of relative position priming observed at this SOA. Grainger et al. interpreted this modulation of the relative position priming effect as a consequence of the presence of a forward mask, in line with recent evidence showing that visual factors such as the type of pattern mask, or the size and luminance of the displayed stimuli, can modulate orthographic priming effects (see Frost, Ahissar, Gotesman & Tayeb, 2003). Nonetheless, it should be taken into account that Grainger et al. used relative position primes that mixed consonants and vowels, and that their set of materials was relatively small, so that the fact that they did not find significant relative position priming effects at 33 ms SOA when a pattern mask was included could be simply due to a lack of power.

The aim of our Experiment 3 was twofold. First, we wanted to test if the relative position priming effect can be found under prime presentation conditions in which the influence of the phonology is rather limited (i.e., at a short SOA of 33 ms). And second, we wanted to explore if the asymmetric subset priming effects that we found for consonants and vowels could be replicated under such presentation conditions. To this end, we presented participants with a large set of target words that could be very briefly preceded (for 33 ms) by masked primes from a relative position priming condition or from a control condition. Furthermore, we included an identity priming condition to assure some significant differences (note that Grainger et al. failed to obtain a significant subset priming effect when a pattern mask was also included).

Method

Participants. Thirty-nine undergraduate students from the University of the Basque Country and the University of La Laguna took part in this experiment in exchange for course credit. None of them had taken part in the previous experiments.

Materials. A total of 216 words taken from the materials used for Experiments 1 and 2 were selected for this experiment. 108 of these words had a vowel as first, third and fifth letters (e.g., *icono*, the Spanish for *icon*). The remaining 108 words had a consonant as first, third and fifth letters (e.g., *licor*, the Spanish for *liquor*). Both groups of words were matched in a pairwise manner for frequency, length and number of orthographic neighbors. Words in the vowel set had a mean frequency of 10.64 (range: 0.18-105.71) appearances per million, a mean length of 5.44 (range: 5-6) letters, and a mean number of 1.8 (0-8) orthographic neighbors. Words in the consonant set had a mean frequency of 12.53 (range: 0.18-99.29) appearances per million, a mean length of 5.44 (range: 5-6) letters, and a mean number of 2.3 (0-11) orthographic neighbors. These words were taken as targets, and could be preceded by prime strings that could either be 1) identical to the targets (e.g., *icono-icono*, *licor-licor*), 2) relative position primes (e.g., *ioo-icono*, *lcr-licor*), or 3) unrelated control strings (e.g., *eaa-icono*, *fvn-licor*). 216 nonwords were also created in order to make lexical decision possible. Three lists of materials were created, so that each target appeared once in each, but each time in a different priming condition. Thirteen participants were assigned to each of the lists.

Procedure. The same procedure as in Experiment 1 was followed, except for prime exposure duration, which was reduced to 33 ms. The whole experiment lasted for around 15 minutes.

Results

Reaction times below 250 ms or above 1500 ms and all the reaction times associated with incorrect responses were excluded from the latency analyses. Mean reaction times and percentages of errors for each experimental condition are presented in Table 3. First, a full ANOVA was performed, following a 2 (Type of letter:

Consonant, Vowel) x 3 (Type of relationship: Identity, Relative position, Unrelated) x 3 (List: List 1, List 2, List 3) design. Second, ANOVAs for the pairwise comparisons with the control prime condition were performed to assess priming effects in the two related prime conditions (Identity, Relative position), considering Type of letter (Consonants, Vowels), Relatedness (Related, Unrelated) and List (List 1, List 2, List 3) as factors.

--- Insert Table 3 here ---

Word data.

The full ANOVA on the latency data showed a main effect of Type of relationship, F1(2,72)=18.54, p<.01; F2(2,420)=14.89, p<.01. The interaction between Type of relationship and Type of letter closely approached significance, F1(1,36)=2.26, p=.11; F2(2,420)=2.70, p=.07.

The full ANOVA on the error data did not show any significant effects or interaction.

Identity. The analyses showed a main effect of Type of letter, F1(1,36)=6.51, p<.02; F2(1,210)=4.61, p<.04. The effect of Relatedness was significant, revealing that words preceded by identical primes were recognized significantly faster (25 ms faster) than words preceded by unrelated primes, F1(1,36)=39.63, p<.01; F2(1,210)=28.58, p<.01. The interaction between the two factors was not significant (both Fs<1 and ps>.65). The analyses on the error rates showed a similar pattern of results, with target words preceded by unrelated primes being recognized less accurately than target words preceded identical primes (a 1.3% difference), F1(1,36)=3.30, p=.08; F2(1,210)=4.81, p<.03. There were no other significant effects (all ps>.45).

Relative position. The analyses showed a main effect of Relatedness, revealing that words in the related subset priming condition were recognized faster than words in the unrelated priming condition, F1(1,36)=4.07, p=.05; F2(1,210)=3.78, p=.05. More importantly, an interaction emerged between Type of letter and Relatedness, F1(1,36)=3.81, p=.06; F2(1,210)=4.48, p<.04. Pairwise comparisons showed that the Relatedness effect was not significant for vowel relative position prime-target pairs that did not differ in the reaction times of the related and unrelated conditions (a -1 ms effect; both Fs<1 and ps>.85). On the contrary, target words preceded by consonant relative position primes were recognized significantly faster (19 ms faster) than target words preceded by unrelated primes, F1(1,36)=6.42, p<.02; F2(1,105)=7.87, p<.01. No significant differences were seen in the error rate analyses (all ps>.16).

Nonword data.

None of the effects or interactions in the full ANOVA on the latency data and the error data was significant.

The results from Experiment 3 were straightforward. The subset priming effect was only significant for the consonant group of words. Hence, when controlling for the influence of phonology the relative position priming effect can still be found for consonants, while this is not the case for vowels. Grainger et al. (2006) also found a relative position priming effect in similar conditions when the pattern mask was not included, but they failed to obtain a significant effect when the mask was presented before the prime (note, however, that they found a trend towards a significant effect in the expected direction when seven-letter targets were used). We believe that their failure to obtain such an effect was probably due to the fact that consonants and vowels were intermixed within the primes, and that the number of items per condition did not yield enough experimental power, since in the present experiment we obtained a significant relative position priming effect for consonant subset primes when a 33 ms prime exposure duration was used and when primes were presented after a pattern mask. Together, the present results and preceding data seem to demonstrate that the relative position priming effect is orthographic in nature (note that Perea and Carreiras, 2006a; 2008, also showed that the nature of the transposed-letter priming effect is not phonological, but orthographic), and that it can be found (for consonant primes) in conditions under which the influence of phonology is limited.

One important aspect of the materials that were used in Experiments 1-3 is that the primes in the vowel conditions included repeated letters in many cases, while the letter repetitions were less frequent in the consonant condition primes (e.g., *ioo* from *icono* vs. *lcr* from *licor*; see Appendix). This is not a surprising fact, since it is the direct consequence of the difference between the number of consonants and vowels in Spanish. This, together with the fact that the most repeated syllabic structure in Spanish is the CV structure, makes it more probable that a word might contain repeated vowels than repeated consonants. One potential explanation for the null priming effects observed in the vowel priming conditions could have derived from this difference in the number of repeated letters in the primes. As noted by Schoonbaert and Grainger (2004) and by Dehaene et al. (2005), in models using open-bigram coding schemes (Grainger & van Heuven, 2003; Whitney, 2001), repeated letters imply repetition at the bigram level. According to these frameworks, the number of different bigrams activated from the prime would be different for primes with repeated and non-repeated letters. For instance, a prime like *lcr* (relative position prime for *licor*) would activate three bigrams (*LC*, *LR* and *CR*), while a prime like *ioo* (relative position prime for *icono*) would activate only two (*IO* and *OO*). If, as we said, the number of repeated vowels will inevitably be greater than the number of repeated consonants due to the restricted number of vowels in the language, then it could be argued that the priming asymmetry that has been found does not correspond to the types of letters we manipulated (consonants vs. vowels), but rather to the fact that less target activation is expected for primes with repeated letters, on the basis of some models with open-bigram encoding mechanisms (see Whitney & Cornelissen, 2008, for a comprehensive discussion of this issue). In Experiment 4 we investigated whether consonant and vowel primes that did not include any repeated letters would still show the priming asymmetry that was found in the preceding experiments.

Experiment 4

Method

Participants. A different pool of thirty undergraduate students from the University of the Basque Country and the University of La Laguna took part in this experiment for course credit. All of them had normal or corrected-to-normal vision.

Materials. A set of 120 Spanish words was selected. All of the words were six or seven letters long (see Appendix). Half of these words included a vowel as second, fourth and sixth letters (e.g., *minero*, the Spanish for *miner*). The mean frequency of these words was 14.19 appearances per million (range: 1.6-205.7), the mean length was 6.63 letters (range: 6-7), and the mean number of orthographic neighbors was 1.18 (range: 0-6). The other half was composed of words that included a consonant as second, fourth and sixth letters (e.g., *plátano*, the Spanish for *banana*). These words were matched to the previous ones in frequency (mean: 17.02; range: 1.4-320.4), length (mean: 6.58; range:

6-7), and number of orthographic neighbors (mean: 1.05; range: 0-5). These words were used as targets and could be preceded 1) by the second, fourth and sixth letters (relative position; e.g., *ieo* - *minero* and *ltn* - *plátano*), 2) by three consonants or vowels that did not appear in the target word (control; e.g., *uau* - *minero* and *sdm* - *plátano*), or 3) by themselves (identity; e.g., *minero* - *minero* and *plátano* - *plátano*). Crucially, none of the related relative position primes included repeated consonants or vowels (e.g., *ieo* and *ltn*). (Note, however, that unrelated subset primes included repeated vowels). In order to make lexical decision possible, 120 nonwords were also created. The same priming conditions as for the words were used for the nonwords. Three lists of materials were created, so that each target appeared once in each, but each time in a different priming condition (relative position, control and identity). Ten participants were assigned to each of the lists.

Procedure. The same procedure as in Experiment 1 was followed. The experiment lasted for around 10 minutes.

Results

Reaction times below 250 ms or above 1500 ms and all the reaction times associated with incorrect responses were excluded from the latency analyses. Mean reaction times and percentages of error for each experimental condition are presented in Table 4. First, a full ANOVA was performed following a 2 (Type of letter: Consonant, Vowel) x 3 (Type of relationship: Identity, Relative position, Unrelated) x 3 (List: List 1, List 2, List 3) design. Second, ANOVAs for the pairwise comparisons with the control prime condition were performed to assess priming effects in the two related prime conditions (Identity, Relative position), considering Type of letter (Consonants, Vowels), Relatedness (Related, Unrelated) and List (List 1, List 2, List 3) as factors.

--- Insert Table 4 here ---

Word data.

The general ANOVA on the latency data showed a main effect of Type of relationship, F1(2,54)=13.84, p<.01; F2(2,228)=16.75, p<.01. The effect of Type of letter was not significant. The interaction between the two factors was not significant, F1(2,54)=2.10, p>.13; F2(2,228)=2.20, p>.11.

The full ANOVA on the error did not show any significant effect.

Identity. Words preceded by identical primes were recognized faster (26 ms faster) than words preceded by unrelated primes, F1(1,27)=26.48, p<.01; F2(1,114)=30.21, p<.01. There were no other significant effects or interactions (all Fs<1 and ps>.40).

The analyses of error rates did not show any significant effects.

Relative position. The Relatedness effect was significant in the analysis by items and closely approached significance in the analysis by participants, F1(1,27)=3.14, p=.09; F2(1,114)=6.72, p<.02. The effect of Type of letter was not significant. Importantly, the interaction between the two factors was significant, F1(1,27)=4.50, p<.05; F2(1,114)=4.64, p<.04. Pairwise comparisons showed that target words that followed consonant subset primes were recognized significantly faster (21 ms faster) than target words that followed unrelated items, F1(1,27)=9.46, p<.01; F2(1,57)=11.79, p<.01. In contrast, there was no significant relative position priming effect when the primes were composed of vowels (a negligible -2 ms effect), with both Fs<1 and ps>.76.

No significant effects were found in the error rate analyses.

Nonword data.

The general ANOVA on the latency data only showed a main effect of Type of letter, indicating that nonwords in the consonant set were recognized significantly faster than nonwords in the vowel set,F1(1,27)=17.95, p<.01; F2(1,114)=13.35, p<.01.

No significant effects were found in the error rate analyses.

The results from Experiment 4 can be summarized as follows: We have satisfactorily replicated the relative position priming asymmetry for consonants and vowels when the related prime strings did not include any repeated letter (*ieo* from *minero* and *ltn* from *plátano*). In the absence of differences in the identity priming effect, the relative position priming condition only produced significant facilitation on target word recognition when the primes consisted of only consonants (a 21 ms priming effect). Hence, it could be assumed that the inclusion of repeated letters in the primes is not responsible *per se* for the vanishing of the priming effect in the vowel relative position priming condition, since the same null effect was found in Experiment 4 with non-repeated vowels as primes. However, it should be noted that even though the presence of repeated letters might not make the priming effect disappear, it could perfectly be the case that primes with repeated letters produce, on average, priming effects of lower magnitude than primes with non-repeated letters. In other words, according to open-bigram models, less activation is expected for primes including repeated letters, and consequently, the magnitude of subset priming effects could be expected to be larger for those primes not including repeated letters than for those including repeated letters. In Experiment 5, in a new attempt to explore the influence of repeated letters in the primes, we included primes with and without repeated letters, both consisting of consonants or of vowels. In order to maximize the possibilities of obtaining differences across conditions, the identity priming condition was not included, so that larger sets of items for the relative position and control conditions could be used.

Experiment 5

Method

Participants. A different group of thirty-two students from the University of La Laguna took part in this experiment for course credit. All of them had normal or corrected-to-normal vision.

Materials. 280 Spanish words were selected as targets. All of them were six or seven letters long (see Appendix). 140 of these words included a vowel as second, fourth and sixth letters (e.g., *dibujo*, the Spanish for *drawing*, and *madera*, the Spanish for *wood*). Half of these words (i.e., 70 words) included non-repeated vowels (e.g., *dibujo*), and the other half included one repeated vowel (e.g., *madera*). These two subsets were matched for mean frequency (non-repeated: mean=16.48, range=1.6-207; repeated: mean=20.02, range=0.7-352.9), length (non-repeated: mean=6.67, range=6-7; repeated: mean=6.74, range=6-7), and mean number of orthographic neighbors (non-repeated: mean=1.14, range=0-6; repeated: mean=1.11, range=0-6). The other set of 140 words was composed of words that included a consonant as second, fourth and sixth letters (e.g., *imagen*, the Spanish for *image,* and *frutero,* the Spanish for *greengrocer*).). Half of these words (i.e., 70 words) included non-repeated consonants (e.g., *imagen*), and the other half included one repeated consonant (e.g., *frutero*). These words were matched between them and to the previous ones in frequency (non-repeated: mean=18.82, range=1.4-320;

repeated: mean=19.27, range=0.71-348), length (non-repeated: mean=6.63, range=6-7; repeated: mean=6.47, range=6-7), and number of orthographic neighbors (non-repeated: mean=1.01, range=0-5; repeated: mean=1.13, range=0-6). These words were used as targets and could be preceded 1) by the second, fourth and sixth letters (relative position; e.g., *iuo* - *dibujo*, *aea* - *madera*, *mgn* - *imagen*, *rtr* - *frutero*), or 2) by three consonants or vowels that did not appear in the target word (control; e.g., *aea* - *dibujo*, *ioi* - *madera*, *dtl* - *imagen*, *lgl* - *frutero*). In order to make lexical decision possible, 280 nonwords were also created. The same priming conditions as for the words were used for the nonwords. Two lists of materials were created, so that each target appeared once in each, but each time in a different priming condition (relative position and control). Sixteen participants were assigned to each of the lists.

Procedure. The same procedure as in Experiment 1 was followed. The experiment lasted for around 20 minutes.

Results

Reaction times below 250 ms or above 1500 ms and all the reaction times associated with incorrect responses were excluded from the latency analyses. Mean reaction times and percentages of error for each experimental condition are presented in Table 5. An ANOVA was performed following a 2 (Type of letter: Consonant, Vowel) x 2 (Type of primes: Repeated letters, Non-repeated letters) x 2 (Relatedness: Related, Unrelated) x 2 (List: List 1, List 2) design.

--- Insert Table 5 here ---

Word data.

The ANOVA on the reaction times showed a main effect of Type of letter that was significant only in the analysis by participants, F1(1,30)=10.91, p<.01; F2(1,272)=2.28, p>.13, showing that words in the consonant subset were recognized faster (12 ms faster) than words in the vowel set. The Relatedness effect was also significant in the analysis by participants, showing that target words preceded by related primes were responded to faster (8 ms faster) than words preceded by unrelated primes, F1(1,30)=6.30, p<.02; F2(1,272)=2.72, p=.10. More importantly, the interaction between these two factors was significant, F1(1,30)=6.01, p<.03; F2(1,272)=4.47, p<.04. Follow-up pairwise comparisons showed that the Relatedness effect was significant for words preceded by consonant primes (a 16 ms effect), F1(1,30)=14.82, p<.01; F2(1,136)=9.52, p<.01. Moreover, the Relatedness effect was similar for repeated and non-repeated consonant priming conditions (13 and 18 ms, respectively; Fs<1 and ps>.65). In contrast, the Relatedness effect was not significant for words preceded by vowel primes (both Fs<1 and ps>.95). The rest of effects or interactions were not significant (all Fs<1 and ps>.32).

The ANOVA on the error data showed that the factor Type of primes significantly interacted with the factor Type of letter in the analysis by participants, F1(1,30)=9.43, p<.01; F2(1,272)=2.69, p=.10. Pairwise comparisons showed that, for targets in the non-repeated letter condition, words in the consonant subset were recognized significantly more accurately than words in the vowel subset (a 2.03% difference), F1(1,30)=5.79, p<.03; F2(1,136)=2.85, p=.09. In contrast, the Type of letter effect was not significant in the repeated letter condition (ps>.15). No other significant effects or interactions were found (all ps>.30).

Nonword data.

The ANOVA on the latency data showed a main effect of Type of primes, F1(1,30)=43.87, p<.001; F2(1,272)=9.11, p<.01, showing that nonwords in the non-repeated letter set were recognized significantly faster (26 ms faster) than nonwords in the repeated prime set. The effect of Type of letter was also significant, F1(1,30)=40.72, p<.001; F2(1,272)=17.55, p<.001, showing that nonwords in the consonant prime set were recognized faster (40 ms faster) than nonwords in the vowel prime set [Footnote 2]. There were no other significant effects or interactions.

As seen from the results of Experiment 5, the consonant relative position priming effects do not notably differ for primes with repeated letters and for primes with non-repeated letters (13 and 18 ms, respectively). Besides, vowel relative position primes were equally ineffective for target word recognition when these included repeated or non-repeated letters (negligible priming effects of 3 and -3 ms, respectively). Thus, apart from replicating the relative position priming asymmetry, we believe that these results (together with those from Experiment 4) rule out an explanation of the asymmetry based on the higher number of repeated vowels in the primes than of repeated consonants. In short, repeated letters in the primes do not modulate the relative position priming effects.

General Discussion

The results obtained in the present experiments can be summarized as follows. First, in five experiments we have consistently replicated a form of subset priming (namely, the relative position priming effect) for consonants. Second, we have consistently shown that this subset priming effect vanishes when the critical letters are vowels. Third, we have presented evidence showing that this consonant-vowel differentiation does not seem to be a consequence of the frequency of the letters, since low frequency consonants produced as much relative priming effect as high-frequency consonants (Experiment 2). Fourth, we have shown that when controlling for the potential influence of phonology (by reducing the prime exposure time), the subset priming asymmetry as a function of letter type is still present (Experiment 3). And fifth, we have ruled out an explanation for this asymmetry based on the presence of more repeated vowels than consonants in the primes (Experiments 4-5).

--- Insert Figure 1 here ---

The pattern of results in these experiments has been very consistent: primes consisting of only consonants facilitated target word recognition while there were null priming effects for primes consisting of only vowels (see Figure 1). What is the underlying reason for this asymmetry? Based on recent findings (Carreiras, Duñabeitia & Molinaro, 2009), we initially proposed that the processing difference could be due to the different lexical constraints imposed by these two entities (consonants and vowels). According to the Lexical Constraint Hypothesis, considering the higher number of consonants as compared to vowels in most languages, it could be expected that simply by means of statistical regularities, primes that are composed only of consonants will highly reduce the number of lexical candidates, thus facilitating lexical access by means of restricting the number of potential competitors. However, in order to accept this explanation, it is necessary to first discard other alternative hypotheses that could, in principle, account for the vowel-consonant difference. One alternative possibility that has been tested in the present study is that the letter-type distinction might rely on the different frequency distribution of vowels (much more frequent) and consonants (less frequent in most cases), which is a natural consequence of the abovementioned argument. In fact, some authors have invoked a frequency explanation to interpret the different saliency of consonants and vowels in visual and auditory word and pseudoword recognition (e.g., Keidel, Jenison, Kluender & Seidenberg, 2007). Keidel et al. proposed that the statistical distribution of letters in the language (i.e., with vowels being much more frequent than consonants) is the origin of the consonant-vowel processing asymmetry. Thus, according to their view, statistical probabilities are the cause of the consonant-vowel differential effect (see also Lupker et al., 2008, as support for this view). In Experiment 2 we tested this interpretation in an experiment that included vowels and high and low-frequency consonants. The results showed that frequency of the letters plays a negligible role in the relative position priming effects for consonants, and that a broader distinction between consonants and vowels seems more suitable in explaining the asymmetric pattern of results. Related consonant primes speeded up target word recognition irrespectively of the frequency of the consonants, while vowel primes did not. In the light of these results, a purely frequency-based explanation does not seem appropriate in accounting for the whole set of results. Furthermore, this argument has been recently reinforced in a study showing that increased letter frequency does not necessarily come hand-by-hand with increased lexical activation (see Dandurand, Grainger, & Duñabeitia, submitted). It should be noted, however, that the overall frequency difference between vowels and high-frequency consonants was significant (p<.001; see Material section of Experiment 2). Hence, considering that in Spanish (as in many other languages) vowels are much more frequent than consonants, it should be acknowledged that the frequency explanation could only hold true by assuming that orthographic encoding is only sensitive to extremely high differences in letter frequency (which would lead to a broad vowel-consonant distinction, but would overlook differences in lower frequency ranges, like high and low-frequency consonants).

Our results from Experiment 2 diverge from previous evidence from a recent study exploring the influence of letter frequency in the transposed-letter similarity effect. Lupker, Perea and Davis (2008) showed that the transposed-letter similarity effect was more robust for low-frequency consonants than for high-frequency consonants, and stated that the frequency difference could account, at least in part, for the observed differential transposed-letter effects (in fact, the 11 ms transposed-letter priming effect for the high-frequency consonants was not significant). Nonetheless, Lupker et al. left the door open to other alternative (or complementary) explanations for vowel-consonant transposed-letter asymmetric effects, such as the potential relationship between vowels and phonology. In Experiment 2 we showed that low and high-frequency consonants contributed in a very similar way to the subset priming effects, which significantly differed from the contribution of vowels, and in Experiment 3 we demonstrated that when controlling for the influence of phonology, the subset priming asymmetry persists. Thus, our results are apparently at odds with those obtained by Lupker et al. However, it should be considered that they found a trend towards a significant effect for the high-frequency consonant transposition (an 11 ms effect), as in Duñabeitia et al. (2006), where a similar effect (10 ms priming) was obtained in a parallel manipulation in Spanish. In consequence, it is not completely clear that the transposed-letter similarity priming effect totally disappears as a mere consequence of increased letter frequency, and consonant-vowel status should also be considered as a potential factor (as Lupker et al. also pointed out). Moreover, the reader should keep in mind that while Lupker et al. tested the impact of letter frequency on the transposability of consonants vs. vowels, we aimed at testing the impact of consonants-only and vowels-only primes in a series of masked subset priming experiments. As a consequence, the two studies used completely different baselines and control conditions (2-letter different versus all letter different), disallowing any direct comparison between them.

Given that most languages have a higher number of consonants than of vowels, it is quite straightforward to assume that in the process of lexical selection consonant identities will be more helpful than vowel identities, since they will provide the reader with more constraining and less redundant orthographic information (i.e., the Lexical Constraint Hypothesis; see Bonatti et al., 2005; Mehler et al., 2006; Toro et al., 2008, for similar claims). According to the Lexical Constraint Hypothesis, there are reasons to believe that consonant identities will be much more determining than vowel identities in the process of searching for a word in the mental lexicon, since they provide useful information for lexical selection processes, whereas vowels do not, or at least, not to the same extent. In this line, it has been proposed that consonants are the main units to access the lexicon, (e.g., Bonatti et al., 2005; Cutler, Sebastián-Gallés, Soler-Vilageliu & Van Ooijen, 2000; Keidel, Jenison, Kluender & Seidenberg, 2007; Nazzi & New, 2007; van Ooijen, 1996). As stated in the Introduction, Nespor, Peña and Mehler (2003) proposed that while the role of vowels is preferentially related to rhythmic and syntactic patterns, the role of consonants is specifically linked to lexical selection and they therefore provide direct cues to the recognition of a word (e.g., Bonatti et al., 2005; Cutler et al., 2000; see also Carreiras, Duñabeitia, & Molinaro, 2009; Carreiras & Price, 2008; van Ooijen, 1996). Hence, it has been proposed that "*consonants may contribute more to word identity*" (Bonatti, Peña, Nespor & Mehler, 2007, p. 924; also Mehler, Peña, Nespor & Bonatti, 2006), and that the mechanisms of orthographic processing are mainly (even though not exclusively) based on consonant detection (Carreiras et al., 2009). Consonants preferentially serve to individuate words, since changing a consonant in a word with another consonant might easily lead to the creation of another existing word. Take, for instance, a frequent Spanish word like *COSA* (thing); the number of orthographic neighbors that can be created by replacing either of the consonants (*C, S*) for other consonants is much higher than the number of orthographic neighbors that can be created by replacing either vowel (*O, A*) with other vowels. According to B-PAL (Davis & Perea, 2005), a program that derives orthographic neighborhood statistics in Spanish, there are up to 15 different words that can be created from *COSA* with a single consonant-by-consonant replacement, in contrast to the 2 words that can be created with a single vowel-by-vowel replacement.

Consonants therefore serve to individuate words, providing useful information for lexical selection processes. In contrast, the information provided by vowels is clearly less lexically constraining. This line of reasoning helps to extend and clarify previous evidence showing consonant-vowel processing differences (Berent & Perfetti, 1995; Caramazza et al., 2000; Carreiras & Price, 2008; Carreiras, Vergara and Perea, 2007, 2009; Carreiras et al, 2009; Cotelli et al., 2003; Cubelli, 1991; Ferreres et al., 2003; Miceli et al., 2004; Perea & Lupker, 2004; Tainturier & Rapp, 2004). However, two points should be mentioned in this respect. First, the fact that consonants are more lexically constraining than vowels does not necessarily imply that there are radical differences regarding the neural representation of vowels and consonants, as if they were two distinctly localized entities in the human brain, as proposed by some authors (see Caramazza et al., 2000). We cannot rule out this possibility in light of the present results, but we believe that other computationally plausible alternative explanations can be considered. These data suggest that the main source of the difference between consonants and vowels is the lexical information, in terms of statistical regularities, provided by each of these types of letters. Second, it could be argued that the encoding of the different letters (consonants or vowels) follows a different time course. This argument has been put forward by some authors (see Berent & Perfetti, 1995, as representatives of this view). Clearly, this assumption needs to be tested, since it cannot be ruled out by the present set of data. However, rather than assuming a totally distinct time course of processing for consonants and vowels, one could assume that the two types of letters are processed similarly at initial stages of letter recognition (e.g., until invariant abstract letter representations have been accessed), and that the number of activated lexical candidates will determine the extent to which a subset prime will exert a facilitative influence on target word processing. Thus, our data can be easily explained by the lexical constraints imposed by the letters that constitute the relative position primes, and there is no need to assume an inherent processing speed difference between the two categories of letters (consonants and vowels). The human reading system may not need to differentiate between letter types during the early stages of visual word recognition, thus processing similarly the consonants and the vowels of a letter string. Nonetheless, once these individual graphemic representations start to be mapped onto lexical representations, the consonant-vowel difference emerges, since the former reduces or constrains the possible set of lexical candidates much more than the latter type of letters.

The present study contributes to refining the extent to which consonants and vowels contribute to orthographic processing, establishing a clear distinction on the basis of the amount of lexical constraint they impose. Consider, for instance, the Spanish lexicon of six-letter words, and the lexical entry *ANIMAL*, preceded by the relative position consonant prime *NML*. As a consequence of coding the consonant identities of the prime following open-bigram principles, the active bigrams would be

NM, *NL* and *ML*, and the lexical candidates that are coincident with these bigrams would be only two (*ANIMAL* and *NORMAL*). In contrast, a vowel-based relative position prime (*AIA*) would lead to a code similar to *AI*, *AA*, *IA* in terms of open-bigrams. This pattern of bigrams is too inefficient for lexical selection, since in a Spanish lexicon too many words would receive feed-forward activation (e.g., *ANIMAL*, but also *SALIDA*, *AMPLIA*, *BAILAR*, *PALIZA*, *AISLAR*, *LATINA*, and many others). Therefore, the active lexical candidates would be less for a consonant relative position subset prime like *NML* than for a prime like *AIA*, and the dispersion of the activation would consequently be smaller in the case of *nml-ANIMAL* than in the case of *aia-ANIMAL*. Thus, the present findings can be accounted for by linking the Lexical Constraint Hypothesis and the mechanisms that led to the observed relative position masked priming effects: A subset masked prime may activate the correct lexical entry (i.e., the target) faster when the prime is based on consonants that when it is based on vowels, and therefore the consonant subset primes will show greater priming effects than the vowel primes.

The Lexical Constraint Hypothesis could, thus, be a comprehensive way of accounting for the present results, and for the vowel-consonant distinction. Further, this hypothesis can account for convergent previous evidence (e.g., Carreiras, Gillon-Dowens, Vergara & Perea, 2009; Carreiras, Vergara & Perea, 2009; Lee, Rayner & Pollatsek, 2001, 2002; New, Araújo & Nazzi, 2008). For instance, New et al. recently conducted a masked priming experiment in which French participants were presented with words preceded by nonwords that shared with them only the consonants (e.g., *duvo-DIVA*) or only the vowels (e.g., *rifa-DIVA*), and showed that priming regarding a control condition (e.g., *rufo-DIVA*) was only found for consonant-related primes (a 18 ms effect). The results in the study by New et al. can be accounted for by the same mechanism that we proposed above, by which, as a consequence of the lexical constraint imposed by consonants, the information contained in consonant combinations will activate the target strings faster than that information contained in vowel combinations.

The present results (and those shown by Carreiras et al., 2009) can be captured by models of orthographic coding that rely on the competitive processes initially described in the Interactive Activation model (McClelland & Rumelhart, 1981; see Davis, 2003, for comprehensive discussion of this issue). Models assuming competitive processes within the network are based on the idea of multiple activated representations in the mental lexicon when an input is provided to the system. The basic idea is that a printed word will activate its corresponding lexical representation, but that neighboring representations will also be activated in this process (see, for instance, Davis & Lupker, 2006; Perry, Lupker, & Davis, 2008). For this reason, competitive models of word processing assume that final target selection results from the competition among the activated representations (e.g., Coltheart et al., 2001; Davis, 2010; Grainger & Jacobs, 1996). Thus, competitive models of visual word recognition can account for the present pattern of data, under the assumption of the smaller competition (due to the constrained number of lexical candidates) triggered by consonant subset primes than by vowel primes. It is expected that the most informative or lexically constraining subset primes will give rise to a reduced number of activated neighboring representations, which would in turn produce reduced competition for selection. In contrast, those subset primes that are not highly lexically constraining (i.e., the vowel primes in the present experiments) will not be very informative and consequently will activate many potential lexical candidates, thus increasing competition for unique target selection. Hence, competitive network-based models of word processing can readily predict the pattern of subset masked priming effects shown in this study for consonant primes.

In spite of this apparent suitability of competitive network-based models of word identification in accounting for the present and parallel sets of data, one of the findings observed casts doubt on whether these models can completely account for the pattern of effects. In Experiments 3 and 4, in which an identity priming condition was included, masked consonant subset priming effects and identity priming effects did not differ from each other, while they significantly differed in the vowel subsets. Interestingly, this same null difference between identity priming and relative position priming for consonants was recently obtained in an ERP study by Carreiras, Duñabeitia and Molinaro (2009). In that study, masked relative position priming for consonants (*frl-farol*) and masked identity priming (*farol-farol*) did not significantly differ from each other in the N250 and N400 components. In contrast, masked vowel subset priming (*aeo-acero*) and masked identity priming (*acero-acero*) were significantly different in the same two components, One potential explanation for this null difference between consonant subset priming and identity priming could rely on a mere lack of statistical power in these experiments, that could have lead to a β-type error (i.e., type II error) by which slight differences between conditions did not result in a significant interaction. (Note that this is a possibility that should be kept in mind especially in masked priming experiments in which effects are typically small). However, if this is not the case and if consonant subset primes and identity primes in fact produce equivalent priming effects, models of orthographic coding and of word identification should necessarily echo this finding, probably assuming the idea of a much greater reliance of the system on consonants than on vowels. An extreme position within this view would be to assume that when a masked prime is presented, only consonants and their information are deeply processed, while vowels are somehow ignored. Hence, primes containing all the targets' consonants (consonant relative position priming condition) would be expected to prime as well as the target letter string itself (identity priming condition), as has been shown in Experiments 3 and 4. Obviously, we cannot give unequivocal support to this assumption in light only of the present results, and we still favor the general idea of lexical constraint as responsible for the pattern of data observed, rather than assuming that vowels are partially neglected during the earliest moments of word identification. Nonetheless, this is an option that should be kept in mind, and efforts should be directed towards clarifying whether the type of letter determines the orthographic coding mechanisms (the consonant-only view), or whether differences between different types of letters emerge at a secondary stage, when the number of lexical candidates matching a given letter input plays a role (the Lexical Constraint Hypothesis). Even though this is a collateral finding that is not the key discovery of the present study, we believe that it deserves future research.

Finally, we wish to stress the relevance of the present findings for models of orthographic encoding that are not directly based on competitive networks or that do not take into account feedback information from the lexical level in the process of letter identification. Recently proposed models (e.g., Dehaene, Cohen, Sigman & Vinckier, 2005; Gómez et al., 2008; Grainger et al., 2006; Grainger & van Heuven, 2003; Whitney, 2001) do not include a letter processing distinction based on the lexical constraints they impose, and so would not directly predict differences with a type of manipulation such as the one in the present study.

Open-bigram models, which seem to readily capture relative position priming effects (e.g., Grainger et al., 2006; Grainger & van Heuven, 2003; Whitney, 2001, among others; see Van Assche & Grainger, 2006, and Grainger, 2008, for review), cannot account for the present set of data that distinguishes between consonant and vowel relative and absolute position priming effects. Open-bigram models propose a coding scheme for left-to-right languages based on the activation of contiguous and non-contiguous left-to-right bigrams (e.g., *NM*, *NL* and *ML* would be some of the bigrams active from the input *ANIMAL*). Therefore, these models can account for the relative position priming effect (for consonants) because it relies on one of the basic principles of the models. However, these models fail to predict the vowel-consonant asymmetry that has been shown in the present study simply because these models do not explicitly take into account different lexical activation patterns imposed by sub-word units. Nonetheless, it should be considered that these models are more or less silent regarding the influence of lexical feedback information on unitary letter and letter cluster processing, since their major focus is on the initial stages of letter identity and position coding. One possibility to establish the consonant-vowel difference within these models would be to consider that the strength of activation of different bigrams or individual letters will depend on the number of possible lexical candidates activated by the combination of those letters (i.e., a lexical constraint), which typically leads to the vowel-consonant distinction (see Bonatti et al, 2007). However, these models in their present form do not include a specific marker of the constraints imposed by top-down factors, such as the lexical constraint imposed by the letters within the string, or other explanations based on the dispersion of the lexical activation as a function of lexical constraint, and this is clearly needed in order to test whether these models can efficiently account for the present pattern of data (see, for instance, Davis, 2010, for a discussion on the potential impact of feedback mechanisms on models of orthographic encoding).

As we have stated, one possible way to reconcile this vowel-consonant distinction with existing computational models of word recognition and orthographic processing might be by attending to the lexical constraints imposed by each type of letter. Considering that the difference between vowels and consonants does not seem to take place at the initial letter coding stages of word processing, but at a secondary stage when the identified graphemes start to be mapped onto lexical representations, we cannot directly assess whether or not orthographic coding schemes can account for these findings, since not all orthographic coding schemes offer a way to quantify the influence of general lexical activity in the lexicon as a function of the lexical candidates activated by a given string (i.e., the complete architecture of a model is needed to fully evaluate interactions between types of letters and lexical activity). As stated before, it should be noted that the account of the present findings based on the lexical constraint imposed by each type of subset primes could potentially be accommodated by models in which either the premises of activation dispersion or lexical competition (or parallel inhibition) are part of the mechanisms leading to effective word recognition. However, these models would have serious difficulties to implement an explanation based on an initial reliance on consonantal information (the consonant-only view). Future research and modelling should shed light on this issue.

In summary, in the present study we have shown that the masked subset priming effect (specifically the relative position priming effect) depends on the type of letter that forms the prime strings. When primes are made up of consonants, they facilitate the recognition of the target word as compared to an unrelated condition. However, a very different picture shows up when the primes are composed of vowels, since no facilitation effect is then observed. Following the Lexical Constraint Hypothesis, we interpret this priming asymmetry by assuming that consonants carry more lexical information (namely, that consonants are more lexically constraining) than vowels.

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Table 1

Mean reaction times and percentages of error for words and nonwords in Experiment 1

	Relative position	Absolute position	Disrupted absolute position	Control
Word targets				
Consonants				
RT	698	696	698	729
PE	4.4	4.2	5.8	6.2
Vowels				
RT	721	718	724	717
PE	5.2	3.9	5.0	5.8
Nonword targets				
Consonants				
RT	866	852	875	875
PE	5.9	5.6	6.5	6.2
Vowels				
RT	787	781	783	797
PE	5.6	3.9	5.4	5.0

Table 2

Mean reaction times and percentages of error for words and nonwords in Experiment 2

	Relative position	Absolute position	Control
Word targets			
Low consonants			
RT	679	685	705
PE	9.5	7.1	9.8
High consonants			
RT	672	675	701
PE	10.4	9.1	10.0
Vowels			
RT	669	675	663
PE	4.9	5.2	4.0
Nonword targets			
Low consonants			
RT	713	696	719
PE	4.8	3.0	3.4
High consonants			
RT	762	759	746
PE	8.9	9.7	7.3
Vowels			
RT	792	773	774
PE	9.1	8.2	10.0

Table 3

Mean reaction times and percentages of error for words and nonwords in Experiment 3

	Identity	Relative position	Control
Word targets			
Consonants			
RT	632	639	658
PE	3.1	3.7	4.9
Vowels			
RT	621	645	644
PE	3.8	3.8	4.5
Nonword targets			
Consonants			
RT	664	657	666
PE	6.4	5.6	5.0
Vowels			
RT	672	662	668
PE	6.4	7.1	6.6

Table 4

Mean reaction times and percentages of error for words and nonwords in Experiment 4

	Identity	Relative position	Control
Word targets			
Consonants			
RT	628	638	659
PE	3.3	4.7	4.0
Vowels			
RT	631	654	652
PE	4.5	6.3	5.5
Nonword targets			
Consonants			
RT	697	701	719
PE	4.6	5.4	5.7
Vowels			
RT	734	739	731
PE	5.9	5.2	5.7

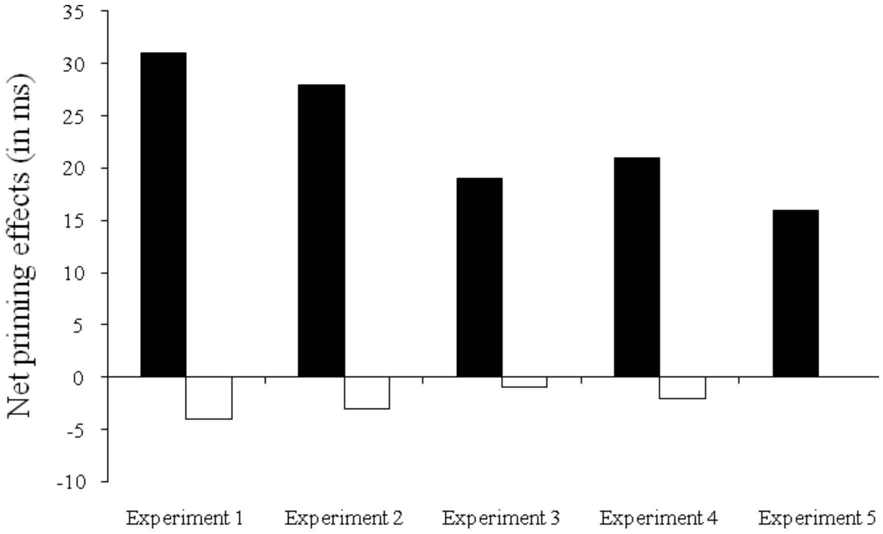
Table 5

Mean reaction times and percentages of error for words and nonwords in Experiment 5

	Relative position	Control
Word targets		
Repeated Consonants		
RT	713	726
PE	6.9	6.3
Non-repeated Consonants		
RT	709	727
PE	4.1	5.1
Repeated Vowels		
RT	727	730
PE	5.4	5.5
Non-repeated Vowels		
RT	735	732
PE	6.3	7.0
Nonword targets		
Repeated Consonants		
RT	855	852
PE	7.9	6.3
Non-repeated Consonants		
RT	820	823
PE	4.6	5.1
Repeated Vowels		
RT	890	885
PE	6.6	6.6
Non-repeated Vowels		
RT	865	868
PE	6.6	7.6

Figure 1

Net relative position priming effects for consonants and vowel in Experiments 1-5. Black bars represent the amount of facilitation for consonant relative position primes, and white bars represent the priming effects for vowel relative position primes. Net priming effects were obtained by subtracting the mean latencies for relative position priming conditions from the mean latencies for the unrelated control conditions.



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Footnotes

Footnote 1. The frequency of appearance of each of the letters that were used in the low-frequency consonant group was: *d*=4.42%, *m*=3.06%, *p*=2.62%, *b*=1.79%, *g*=1.70%, *v*=1.23%, *f*=1.12%, *z*=0.68%, *j*=0.55%. The frequency of appearance of each of the letters that were used in the high-frequency consonant group was: *r*=8.99%, *n*=6.16%, *c*=5.63%, *t*=5.53%, *s*=4.70%, *l*=4.68%. The frequency of appearance of each of the vowels was: *a*=15.01%, *o*=9.90%, *e*=9.12%, *i*=8.47%, *u*=3.13%.

Footnote 2. It is noteworthy that in Experiments 1, 2, 4 and 5, nonwords in the consonant set were responded to significantly faster than nonwords in the vowel set. As explained in the Materials section of Experiment 1, the nonwords kept the same structure as the real words, and were created by replacing the consonants from the vowel word subset, or by replacing the vowels from the consonant word subset. Thus, there are no obvious *a priori* reasons to expect such a RT difference between the different sets of nonwords. Speculatively, following the Lexical Constraint Hypothesis, one could argue that these differences might rely on the fact that nonwords in the consonant sets (e.g., *furel*) would activate less lexical candidates than nonwords in the vowel sets (e.g., *apevo*), simply on the basis of the higher number of consonants in the former than in the latter sets. Considering that the amount of active lexical candidates can be determined by the number of consonants in a string (i.e., less active candidates the more consonants a string includes), the lexical dispersion or the word-likeliness of a nonword could be different as a function of the number of consonants that form it. Even very tentatively, we believe that this line of reasoning could explain the effects found for the nonword sets. However, it is also perfectly possible that these differences emerge from uncontrolled variables that might have led to differences between the nonword sets.

Appendix

List of words used in Experiment 1

VOWEL GROUP			*CONSONANT GROUP*		
acebo	aguda	apodo	dolor	veloz	casar
arado	aguja	enero	cenar	feroz	bozal
orujo	abono	alero	vigor	mural	tenor
apoyo	amago	amado	pedal	robot	lavar
ajeno	ocaso	arena	bedel	licor	tarot
aleta	abuso	ozono	relax	letal	nacer
acera	opaco	atajo	caber	mamut	rumor
aliño	ojera	aroma	vejez	debut	vapor
abeto	ahogo	etapa	besar	rival	legal
apuro	azada	osado	jugar	mojar	misil
erizo	acero	avena	bañar	pañal	picor
apaño	obesa	oreja	tumor	fusil	tenis
orina	ameno	amiga	farol	coger	tapiz
anexo	oruga	oveja	cazar	bazar	metal
ameba	abajo	atada	rural	honor	babor
abeja	enano	ayuno	peral	vocal	local
ilusa	araña	asado	matiz	dedal	fugaz
oliva	asilo	acoso	civil	matar	hedor
aviso	azote	otoño	pubis	tutor	fijar
axila	icono	usada	polen	pudor	gafas

List of words used in Experiment 2

VOWEL GROUP		*HIGH-FREQUENCY CONSONANT GROUP*		*LOW-FREQUENCY CONSONANT GROUP*	
oxidar	evadir	cocina	túnica	movido	fabada
adorar	anular	solana	tetera	bajeza	dopado
editar	asador	canoso	sereno	pijama	bajada
ayunar	azahar	culata	sátiro	pedido	vejiga
afinar	apagar	célula	cateto	dopaje	bebida
operar	alejar	soneto	lírica	debido	bebido
alisar	acudir	salero	litera	mojado	mugido
ayudar	aridez	locura	cólera	mazazo	pegada
opinar	exigir	coleta	salina	gemido	debajo
eludir	arañar	risita	sutura	viveza	papada
emisor	anotar	casaca	solera	medida	jugada
animal	asomar	recelo	ruleta	pagado	mimada
agotar	emitir	título	salita	fugada	bodega
animar	orinar	latino	casino	dibujo	dejada
avisar	acusar	tirana	caseta	pijada	fijeza

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omitir
avidez

alabar
amasar
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atacar
orinal
alojar
educar
elegir
asumir

ranura
careta
sonoro
cosaco
rótulo
sótano
sirena
tutela
corona

canica
torero
casero
receta
colina
rutina
casera
sotana
suceso

bóveda
bobada
debida
pagada
gazapo
pedazo
gozada
pomada
dejado

fumada
mojada
fijado
bufido
movida
vivido
fijada
mimado
pegado

List of words used in Experiment 4

CONSONANT GROUP		*VOWEL GROUP*	
emisor	azucena	rebaño	depurar
aludir	azafata	diseño	tijeras
trípode	acatar	camino	relato
gráfico	bragas	derivar	toxina
eficaz	inglés	tirador	retiro
anular	anchura	bodega	penuria
ocupar	platino	simular	suponer
chinas	agotar	bohemia	decano
plácido	adivino	reposar	europa
abogada	agitar	parido	solidez
tráfico	irónica	felinos	desamor
adivina	abusar	jugosa	senado
llovido	probeta	bonita	verano
granizo	chorizo	genital	sacudir
umbral	origen	sujetar	revisor
imagen	acabada	felino	fusilar
granate	glucosa	relucir	cotizar
alegar	evocar	figurar	debatir
enchufe	plátano	mineral	resumir
crónico	esclava	lujosa	aerobic
asumir	abonado	litoral	minero
imitar	educar	penosa	coleta
astral	ingrata	rebotar	demorar
erizado	abatido	dibujo	pilares
archivo	apurado	celador	tiroteo
iceberg	además	bohemio	sucesor
cretino	oponer	pelota	rosario
alameda	crecer	rizado	cocinar
acoger	irónico	soledad	titubeo

probado	chupada	bidones	recital

List of words used in Experiment 5

CONSONANT GROUP		*VOWEL GROUP*	
REPEATED	*NON-REPEATED*	*REPEATED*	*NON-REPEATED*
grosera	abusar	domador	verano
ayudado	archivo	canario	revisar
frutero	abogada	taponar	jugosa
oradora	erótica	demoler	suponer
aludida	ocupar	remitir	coleta
grosero	anchura	remover	relato
global	amoroso	razonar	bidones
pradera	granizo	pareja	rizado
ostras	platino	jubilar	litoral
añadido	esclavo	semanal	rebaño
ilegal	llovido	solapa	sucesor
trazar	erizado	patinar	bodega
arañar	crónico	colocar	mineral
grosor	trípode	definir	pelota
probar	alameda	batuta	soledad
unidad	adivina	tocino	reposar
apetito	aludir	sofocar	decano
brasero	esclava	semana	diseño
granero	umbral	regalar	pilares
orinar	acatar	malaria	varonil
asesora	ingrata	paridad	relucir
crisis	además	capilar	bonita
ayudada	azafata	renegar	sujetar
clavel	cretino	famosas	desamor
evasiva	chinas	tomada	camino
añorar	acabada	digital	resumir
trotar	irónico	severa	solidez
frenar	gráfico	diluvio	fusilar
trepar	probado	rematar	figurar
anónimo	imagen	volador	debatir
apurar	chupada	cavidad	cotizar
plural	cruzada	recoger	rosario
añadida	bragas	caseta	retirar
anónima	asumir	lateral	terapia

adosado
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educado
educada
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asesino
privar
asesor
floral
tragar
aludido
primer
astros
asesina
tratar
cruzar
unánime
emblema
adorar
epopeya
entrar
fregar
aleluya
llorar
evasivo
florero
enanas
tramar
atónito
crecer
avivar
operar
primero
adosada
trasera
grabar

emisor
irónica
anular
oponer
educar
agitar
plátano
chorizo
eficaz
crecer
probeta
inglés
adivino
tráfico
apenas
alegar
agotar
azucena
apurado
esófago
plácido
glucosa
origen
emisora
abatido
granate
evocar
promesa
imitar
enchufe
abonado
iceberg
astral
acoger
clínico
atómica

butaca
decidir
rehacer
bulimia
piloto
rebajas
coronel
carecer
serenar
denegar
nitidez
tenedor
lujuria
soñador
parador
cabeza
suceder
revivir
marina
cometer
habitar
divino
remoto
divisar
vegetal
madera
cubana
separar
someter
militar
familia
pesadez
molino
falacia
perejil
fatiga

diseñar
felino
bohemia
toxina
celador
bohemio
penosa
tiroteo
tirador
titubeo
dibujo
retiro
europa
penuria
tijeras
lujosa
sacudir
aerobic
dinero
demorar
horario
minero
revisor
senado
simular
recital
secular
depurar
genital
derivar
parido
cocinar
rebotar
felinos
deducir
comedia