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An Investigation of the Role of Grapheme Units in Word Recognition

Stephen J. Lupker[1]

Joana Acha[2, 3]

Colin J. Davis[4]

and

Manuel Perea[5]

[1] University of Western Ontario

[2] Basque Center on Cognition, Brain, and Language

[3] University of the Basque Country

[4] Royal Holloway, University of London

[5] Universitat de València

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Address:
Stephen J. Lupker
Department of Psychology
University of Western Ontario
London, Ontario
N6A 5C2
Canada
email: lupker@uwo.ca
phone: 519 661-2111 x84700

Abstract

In most current models of word recognition, the word recognition process is assumed to be driven by the activation of letter units (i.e., that letters are the perceptual units in reading). An alternative possibility is that the word recognition process is driven by the activation of grapheme units, that is, that graphemes, rather than letters, are the building blocks of reading. If so, there must be representational units for multi-letter graphemes like CH and PH which play a key role in this process. We examined this idea in four masked priming experiments. Primes were created by transposing, replacing entirely or removing one component of either multi-letter graphemes or two adjacent letters that each represented a grapheme, using both English and Spanish stimuli. In none of the experiments was there any evidence of differential priming effects depending on whether the two letters being manipulated formed a single grapheme or formed two separate graphemes. These data are most consistent with the idea that multi-letter graphemes have no special status at the earliest stages of word processing and, therefore, that word recognition is, indeed, driven by the activation of units for individual letters.

Keywords: graphemes, masked priming, word recognition, transposed letters

An Investigation of the Role of Grapheme Units in Word Recognition

Phonemes are defined as the smallest sound units in a language, whereas graphemes are defined as the letter-based units that represent phonemes. Often, these units consist of a single letter (e.g., the letter B and the phoneme /b/). In some cases, however, a grapheme involves two letters (e.g., the bigram CH representing the phoneme /J/). A question that researchers have been addressing recently is, what are the processing implications of the existence of multi-letter graphemes.

There are now a considerable number of published studies suggesting that multi-letter graphemes do have a special status with, for example, Tainturier and Rapp (2004) suggested that multi-letter graphemes are represented by units in the sublexical system. One source of support for this conclusion comes from their examination of errors made by individuals with graphemic buffer impairments (see Rapp & Kong, 2002; and Buchwald & Rapp, 2004, for more information about the graphemic buffer). Those individuals made fewer letter-transposition errors on consonant graphemes like CH than on control (i.e., two-grapheme) bigrams like CR. A second source of support comes from the demonstration that word identification and naming latencies are longer for 5 letter words with 3 graphemes/phonemes (ROUTE) than for 5 letter words with 5 graphemes/phonemes (CRISP) (Rastle & Coltheart, 1998; Rey, Jacobs, Schmidt-Weigand & Ziegler, 1998; Rey & Schiller, 2005). These particular results suggest that letter pairs making up a grapheme must be combined by the processing system in order for a word to be read, a process that takes time and effort. Other support comes from Rey, Ziegler and Jacobs's (2000) and Marinus and de Jong's (2011) demonstrations that it is harder to detect the presence of a target letter when it is embedded in a multi-letter grapheme (detect A in COAST) than when it is not (detect A in STAND). Finally, Havelka and Frankish (2010) have reported that, in a lexical decision experiment, case mixing manipulations that divide multi-letter graphemes (e.g., cOaSt) produce longer latencies than case mixing manipulations that do not (e.g., cOAst).

Based on these types of results, a number of authors have claimed that grapheme units are “perceptual” or “functional” reading units that drive the early stages of visual word recognition (e.g., Havelka & Frankish, 2010; Marinus & de Jong, 2011; Rey et al., 2000), although the precise role that these units are assumed to play was not fully specified by these authors. In itself, the claim that the reading system represents multi-letter graphemes is uncontroversial. Such representations are commonplace in well-known models of visual word recognition (e.g., Coltheart et al., 2001; Perry et al., 2010; Plaut et al., 1996; Zorzi et al., 1998). However, the idea that grapheme units are perceptual reading units appears to be a stronger claim about the architecture of the visual word recognition system.

This distinction can be illustrated with reference to two different versions of a dual-route model of visual word recognition (see Figure 1). Within a dual-route framework, one can ask the question, “At what point do the two routes diverge?” Or to put it another way, “What are the largest common units shared by the two routes?” The model illustrated on the left-hand side of Figure 1 illustrates what might be considered the standard approach, according to which the largest common units shared by the two routes are letter units. This model includes grapheme units, but they are assumed to be an intermediate level of representation between letter units and phonologically-based units and, hence, their role is to activate phonology rather than to activate word units.

This letter-input approach is the one that is assumed in most computational implementations of the dual-route framework, as in the DRC model (Coltheart et al., 2001), the CDP and CDP++ models (Perry et al., 2010; Zorzi et al., 1998), and the bimodal interactive-activation model (Diependaele, Ziegler & Grainger, 2010). Furthermore, most models that attempt to describe the early stages of visual word recognition (i.e., orthographic coding/lexical activation models) do not assume the existence of grapheme units (e.g., Davis, 2010; Gomez, Ratcliff & Perea, 2008; Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981; Norris, Kinoshita & van Casteren, 2010; Paap, Newsome, McDonald & Schvaneveldt, 1982; Whitney, 2001). Some of the latter models do posit multi-letter orthographic units, specifically, the highly influential open-bigram models (e.g., Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger & van Heuven, 2003; Grainger, Granier, Farioli, Van Assche, & van Heuven, 2006; Schoonbaert & Grainger, 2004; Whitney, 2001, 2004) which assume a level of representation between the letter and word level in which the units represent all the possible letter pairs. It is these units that drive activation of word units. The point to note, however, is that the multi-letter units in these models are assumed to represent all letter pairs, not simply those pairs corresponding to multi-letter graphemes.[1]

The model illustrated on the right-hand side of Figure 1 illustrates an alternative solution, according to which the largest common units shared by the two routes are grapheme units. Indeed, such an assumption was made in the first computational implementation of the dual-route framework (Reggia, Marsland & Berndt, 1988). In this model, the input layer is a set of position-specific grapheme units. These units code 168 different possible graphemes, including multi-letter graphemes like CH, OU and EIGH. Each grapheme unit has two sets of output connections, one to phoneme nodes (the grapheme-phoneme conversion route) and one to word nodes (the lexical route; see Figure 4, Reggia et al., 1988). One rationale for such a solution could be that the use of grapheme units as inputs to the lexical route helps to increase the efficiency of the orthographic code (e.g., coding SCHOOL requires only three graphemes rather than six letters). A further rationale might be that the nature of the orthographic units developed during reading acquisition is constrained by phonological representations (cf. Perry et al., 2010; Plaut et al., 1996).

Although Figure 1 illustrates the distinction between letter-input and grapheme-input models of visual word recognition with regard to dual-route framework, the same issue arises for models in the triangle framework (e.g., Seidenberg & McClelland, 1989; Plaut et al., 1996). In these models, a common set of orthographic input representations projects along one vertex of the triangle to phonological representations and along another vertex to semantic representations. According to Plaut et al. (1996), these orthographic input representations are grapheme units. In their implemented model, the input layer consists of 105 grapheme units. Note, however, that this assumption is not a necessary feature of models in the triangle framework. For example, a subsequent model proposed by Harm and Seidenberg (1999) assumed that the orthographic input layer codes position-specific letter units.

The question addressed in the present research is not, therefore, whether there are any units at all in the reading system representing multi-level graphemes. The fact that readers are able to recognize that, for example, the digraph CH should be pronounced /J/ means that there must be phoneme units for multi-level graphemes somewhere in the system. Rather, the question is whether it is necessary for models of word recognition to give grapheme units a central role in the word recognition process. That is, do grapheme units provide the input to both the lexical and nonlexical routes (in dual-route models) or in the mappings from orthography to both phonology and meaning (in triangle models)? If it can be demonstrated that graphemes do represent the “perceptual units” driving word recognition, many of the existing computational models of visual word recognition will have to be modified.

An empirical demonstration supporting a grapheme-input model would, at the very least, require eliminating any explanation of those results based on the recruitment of phonological information. Unfortunately, it is somewhat difficult to argue that any of the evidence cited above satisfies that criterion. Many of the results cited above, for example, come from experiments in which the task is naming, a task that clearly requires the retrieval of phonological information. The letter search experiments (Marinus & de Jong, 2011; Rey et al., 2000) are not subject to this same criticism, however, it seems quite likely that phonological information plays at least some role in these types of tasks (e.g., Ziegler & Jacobs, 1995). That is, a letter search for an A is likely a multi-pronged search for both the letter A and the phoneme /{/. Since only the former is in the word COAST, that may make it more difficult to respond positively than when both the letter and phoneme are in the target word (i.e., when searching for A in STAND). This problem, of course, would essentially be restricted to searches for the second letter in a multi-letter grapheme which was true in most of these experiments. The only experiment demonstrating an effect when searching for the initial letter in a multi-letter grapheme is Experiment 2 in Rey et al. (2000) in which they reported that it took longer to find the O in FLOAT than in SLOPE. Brand, Giroux, Puijalon and Rey (2007), however, were not able to replicate this effect in their Experiment 3 while at the same time nicely replicating the effect when the search involved the second letter in multi-letter graphemes (e.g., is there an A in COAST versus STAND?). (See also Ziegler and Jacobs (1995) for a demonstration of the difficulty in finding a letter in a nonword if that letter is the second letter in a multi-letter grapheme.)

Finally, a similar issue arises when considering case mixing experiments. Case mixing involves the presentation of a visually unfamiliar stimulus. Although this manipulation has no differential impact when the stimuli are presented as masked primes (e.g., Forster, 1998), as Mayall, Humphreys and Olson (1997) have noted, with clearly visible stimuli, this particular manipulation seems to force readers to automatically group letters together based on similarity of size and case. As a result, completing the (lexical decision) task requires readers to invoke processes not involved in normal reading. For example, making a lexical decision response to cOaSt or cOAst may be, to a large degree, based on successfully generating a phonological code for the letter string that matches a lexical code in a reader's phonological lexicon. For cOaSt, this process would be somewhat more difficult (than for cOAst) because of the difficulty of separating the O from the S and linking the O together with the a and the S together with the t in order to produce the correct phonological code. The present experiments were, therefore, designed to examine this issue using a procedure/task in which the contrast between a stimulus containing a multi-letter grapheme and a stimulus that does not is less likely to be affected by the recruitment of phonological information in order to perform the task.

In recent years, the masked priming paradigm (Forster & Davis, 1984) has been used extensively to investigate questions concerning orthographic coding (e.g., Davis & Lupker, 2006; Grainger, Granier, Farioli, Van Assche & van Heuven, 2006; Lupker & Davis, 2009; Perea & Lupker, 2003; 2004; Perry, Lupker & Davis, 2008; Schoonbaert & Grainger, 2004). The basic premise of this research is that there is a fairly direct (although not perfect) relationship between prime-target similarity at the orthographic level and the size of the priming effect. For present purposes, the basic idea is that, if word recognition is based on the activation of grapheme units, disturbing the letters in a multi-letter grapheme when creating a prime should have costs which will be different than the costs of disturbing letters that constitute two graphemes. (A similar line of reasoning has been employed in experiments examining the cost of disturbing morphemes in the course of visual-word recognition, see Christianson, Johnson and Rayner (2005) and Perea and Carreiras (2006).) [2]

In the present experiments, we disturbed multi-letter graphemes in a number of ways. In the first experiment, conducted in English, we contrasted the priming effect created by a prime in which a multi-letter grapheme has been replaced (e.g, the one-grapheme condition: amxxnt-AMOUNT) with the priming effect created by a prime in which one letter in a multi-letter grapheme and a neighboring letter/grapheme have been replaced (e.g., the two-grapheme condition: axxunt-AMOUNT). The latencies produced in these two conditions were compared to the latencies in their respective control conditions to measure the priming effects obtained. A word like AMOUNT has 5 graphemes. If grapheme units are central to the word recognition process, a word prime in which a multi-letter grapheme has been replaced (i.e., amxxnt) still shares 4 graphemes with its target (i.e., AMOUNT) which should make it a reasonably effective prime. In contrast, a prime like axxunt shares only 3 graphemes with AMOUNT as well as having a grapheme not actually in AMOUNT (the "u" grapheme), which should make it a much less effective prime (Grainger, 2008; Lupker & Davis, 2009; Schoonbaert & Grainger, 2004). In contrast, if the orthographic units driving word recognition are all letter-based, there should be no difference in the priming effects from the two prime types.

One aspect peculiar to Experiment 1 should be noted. All of the multi-letter graphemes used were multi-vowel graphemes. A reasonable proportion of the prior work (e.g., Havelka & Frankish, 2010; Marinus & de Jong, 2011) has focused on multi-vowel graphemes and, therefore, it was felt to be important to investigate them in the present research as well. In our subsequent experiments, however, only multi-consonant graphemes were used. The reason is that the main manipulation in those experiments involved disturbing graphemes by transposing letters. When primes are created by transposing vowels, even when they are nonadjacent vowels and, therefore, do not form a grapheme (e.g., cisano-CASINO) the resulting letter strings tends to be no more effective primes than primes created by simply replacing those vowels (e.g., cesuno-CASINO, Perea & Lupker, 2004). Such is not true for consonants which show much larger priming effects when letters are transposed than when they are replaced (the "transposed-letter prime advantage"). Because this difference between transposing and replacing letters is a key contrast in Experiments 2, 3 and 4, only multi-consonant graphemes were used in those experiments.

A final point to note is that, even in the manipulation involved in Experiment 1, the use of multi-vowel graphemes did create a small issue. The primes in the one-grapheme condition (e.g., amxxnt for AMOUNT or prxxst for PRIEST) inevitably maintained one more consonant than the primes in the two-grapheme condition (e.g., axxunt or prixxt). In general, primes that maintain consonants are better primes than primes that maintain vowels (New, Araújo & Nazzi, 2008). Therefore, the one-grapheme condition may have had a slight advantage over the two-grapheme condition for reasons unrelated to the issue being investigated here (i.e., the question of whether units for multi-letter graphemes play a role in word recognition). To look ahead slightly, the failure to observe a difference in the size of the priming effects in the two conditions in Experiment 1indicates that this difference in terms of the number of consonants maintained in the primes was not a crucial one.

As just noted, in the remainder of the experiments, we added a slightly different type of manipulation to disturb multi-letter graphemes, transposing letters. Further, unlike in Experiment 1, in each of these experiments a second set of words was selected to create the two-grapheme (control) condition. The manipulations done to the two letters in multi-letter grapheme words were also done to pairs of letters in these words (e.g., two single-letter graphemes were transposed). As noted, typically, transposed-letter (TL) primes involving consonants produce reasonable size priming effects (O'Connor & Forster, 1981; Perea & Lupker, 2003; 2004; Schoonbaert & Grainger, 2004; Van der Haegen, Brysbaert & Davis 2009) although they rarely produce priming at the same level as produced by identity primes, indicating that maintaining letter order is useful but not crucial in producing an effective prime. A potentially key distinction between transposing letters of a multi-letter grapheme and transposing letters that create two graphemes is that, in the former case, there is no transposition of grapheme units. That is, the grapheme order in anhtem (ANTHEM) is maintained whereas the grapheme order in emlbem (EMBLEM – a two-grapheme control word) is not. Therefore, if grapheme units play a key role in word recognition, one would expect more priming when the letters in a multi-letter grapheme are transposed than when letters that make up two separate graphemes are transposed.

Also re-examined in Experiment 2 was the impact of replacement letter (RL) primes. As in Experiment 1, when both letters in a multi-letter grapheme are replaced the prime and target differ in only a single grapheme. In contrast, when two letters are replaced in a word in the two-grapheme condition, the prime and target differ in two graphemes. Therefore, as in Experiment 1, one would expect that there would be more priming when a multi-letter grapheme is replaced (the one-grapheme condition) than when two separate letters are replaced (the two-grapheme condition).[3]

Experiment 2 was carried out in English. Experiments 3 was a parallel experiment carried out in Spanish. Because Spanish is an orthographically shallow language, the expectation was that phonology would have more of an impact on the nature of orthographic representations than in English, which is a somewhat deeper language. In Spanish, there are only two multi-letter graphemes that one can use in this type of situation, CH and QU. Because the CH grapheme involves two consonants, the impact of transposing or replacing CH was investigated in Experiment 3 (with those effects being compared to the impact of transposing or replacing letters that do not form multi-letter graphemes).

Finally, Experiment 4, also carried out in Spanish, involved two new manipulations which again allowed a contrast between words with multi-letter graphemes and words without. One was again based on a comparison between transposed-letter and replacement-letter primes, except that, in multi-letter grapheme words, the letters in question were the final letter in the grapheme and the following letter (mecehro-MECHERO vs menedro-MECHERO). Both of these changes involve eliminating the multi-letter grapheme and adding two new incorrect graphemes (i.e., one for "c" and one for "h" in mecehro as well as one for the "n" and one for the "d" in menedro). As a result, transposed-letter and replacement-letter primes for these words should be relatively ineffective and certainly should not be differentially effective (i.e., there should be no transposed-letter prime advantage). In contrast, when the letters being transposed or replaced do not form a multi-letter grapheme (e.g., secerto-SECRETO vs senesto-SECRETO), the standard transposed-letter prime advantage should be observed (i.e., for these words, the pattern in Experiment 4 should be identical to that in Experiment 3).

Also included in these experiments were two other conditions which essentially act as a type of control manipulation to evaluate a potential alternative account. One involved deleting the second letter of the grapheme (e.g., mecero-MECHERO) and the other involved replacing the multi-letter grapheme by a single letter grapheme (e.g., menero-MECHERO). The purpose of the deleted-letter primes was to focus on the possibility that a single letter in a multi-letter grapheme may partially activate that grapheme's unit (a possibility that could impact the interpretation of the contrast between the transposed- (i.e., mecehro) and replacement-letter primes (i.e., menedro) in this experiment). If single letters do have the ability to activate units for multi-letter graphemes, one would expect these deleted-letter primes to be quite effective primes for words containing multi-letter graphemes (in contrast to when both letters of the grapheme have been replaced by a new single letter). Words without multi-letter graphemes would receive no such benefit.

Experiment 1

Method

Participants. The participants were 48 undergraduates from Royal Holloway, University of London who received course credit or a small payment for their participation. All were native speakers of English and reported having normal or corrected-to-normal vision.

Stimuli and Apparatus. The target stimuli were 60 six-letter words and 60 orthographically legal, six-letter nonwords. Each of the stimuli contained a medial vowel digraph (e.g., EA, OU, etc.). The nonwords were constructed by changing two letters of each of the target words (e.g., BLEACH => BREASH). The mean frequency of the target words was 37.3 per million (CELEX written frequency, range = 1-612). The mean neighborhood size (obtained from N-Watch, Davis, 2005) was 1.0 (range = 0-5) for the word targets and 0.4 for the nonword targets (range = 0-3).

There were four prime conditions, corresponding to a 2 (Number of Graphemes Changed: one, two) x 2 (Relatedness: related, unrelated) design. Related primes were formed by replacing two letters of the target word with “xx”, such that only the target’s multi-letter grapheme was affected (e.g., BLEACH => blxxch) or two graphemes, including the multi-letter grapheme, were affected (e.g., BLEACH => bxxach). The average ordinal position of the substituted letters in these two conditions was matched. The unrelated primes were formed by changing the corresponding letters of an unrelated word; for example, the unrelated primes for the target BLEACH were trxxty and txxaty. Each nonword target was associated with only a single prime, which was formed by replacing two medial letters with “xx”. Four different counterbalanced versions of the experiment were designed, so that each participant saw a given target word only once, paired with one of its four primes; twelve participants completed each version of the experiment.

The experiment was run using DMDX experimental software produced by Forster and Forster (2003). Stimuli were presented on a SyncMaster monitor (Model No. 753DF). Presentation was controlled by an IBM-clone Intel Pentium. Stimuli appeared as black characters on a white background. Responses to stimuli were made by pressing one of two buttons on a custom made button box.

Procedure. Participants were run individually. Each participant sat approximately 18 inches in front of the computer screen. Participants were instructed to respond to strings of letters presented on the computer screen by pressing one button if the letters spelled an English word or another button if the letters did not spell a word. They were also told that a string of number signs (i.e., “######”) would appear prior to the string of letters. They were not told of the existence of the prime. They were also told to respond to each target as quickly and as accurately as possible.

On each trial the participants saw the string of number signs for 500 ms followed by the presentation of the prime for 50 ms in lower case letters. The target then appeared in upper case for either three seconds or until the participant responded. All stimuli were presented in 12 point Arial font.

Participants performed twelve practice trials before beginning the experiment and were given the opportunity both during the practice trials and immediately afterward to ask the experimenter any questions in order to resolve any confusion concerning what was required.

Results

The analysis of reaction times excluded the 6.6% of trials on which participants made errors. Of the remaining 5382 trials, 6 trials on which reaction times were longer than 1500 ms (3 word trials and 3 nonword trials) and one word trial on which the reaction time was less than 250 ms were also excluded from the analysis.

Mean latencies and error rates for word targets from the subject analysis are shown in Table 1. The data were analysed using ANOVAs based on a 2 (Number of Graphemes Changed: one vs two) x 2 (Relatedness: related vs unrelated) x 4 (List: list 1, 2, 3, or 4) design. Number of Graphemes Changed and Relatedness are both within-subject and within-item factors. List is a between-subject and between-item factor. List was included as a factor in the analysis in order to extract variance due to the method of counterbalancing, following the procedure recommended by Pollatsek and Well (1995). We conducted separate analyses treating either subjects (F_1) or items (F_2) as a random factor.

Word latencies. The analysis of correct latencies revealed a significant main effect of Relatedness, $F_1(1, 44) = 24.57$, $MSe = 664.7$, $p<.001$, $F_2(1, 56) = 20.97$, $MSe = 983.5$, $p<.001$. Responses to targets preceded by related primes were faster than responses to targets preceded by unrelated primes. There was no main effect of the Number of Graphemes Changed, $F_1(1,44)=0.84$, $MSe = 811.55$, $p>.30$, $F_2(1,56)=1.09$, $MSe =844$, $p>.30$. Critically, there was no hint of a significant interaction of Relatedness and Number of Graphemes Changed, $F_1(1,44)=0.24$, $MSe = 626.96$, $p>.50$, $F_2(1,56)=0.12$, $MSe = 983.5$, $p>.50$.

Word errors. The analysis of error rates showed nonsignificant main effects of Relatedness, $F_1(1, 44) = 1.86$, $MSe = 0.0036$, $p>.15$, $F_2(1, 56) = 1.89$, $MSe =$

0.0046, $p>.15$, and Number of Graphemes Changed, $F_1(1, 44) = 0.13$, $MSe = 0.0017$, $p>.50$, $F_2(1, 56) = 0.07$, $MSe = 0.0030$, $p>.50$. The interaction of these factors was also not significant, although there was a trend towards significance in the items analysis, $F_1(1, 44) = 2.48$, $MSe = 0.0050$, $p<.15$, $F_2(1, 56) = 3.31$, $MSe = 0.0048$, $p<.10$ due to the fact that there was no priming effect for the two-grapheme target primes and a 2% priming effect (4% errors in the related condition, 6% errors in the unrelated condition) for the one-grapheme target primes.

Nonword Targets. The mean correct reaction time for nonword targets was 584 ms, and the mean error rate was 7.5%.

Discussion

If grapheme units (rather than letter units) drive the word recognition process, primes like amxxnt preserve 4 out of 5 units in AMOUNT while primes like axxunt preserve only 3 out of 5 units in AMOUNT (as well as activating a grapheme unit not involved in the encoding of AMOUNT, the unit for “u”). Therefore, one would expect the former primes to be more effective than the latter. In Experiment 1, there was no statistical evidence supporting this prediction.

Experiment 2

Although the interaction in Experiment 1 was far from significant, the amxxnt primes did produce a numerically larger priming effect than the axxunt primes (in both the error and latency data). If this difference were real, it would be consistent with the idea that there are representational units for multi-letter graphemes which affect the word recognition process. Such small differences, however, could also have been due to the fact that the one-grapheme primes maintained one more consonant than the two-grapheme primes (New et al., 2008). In Experiment 2, we re-examined the question of grapheme units driving the word recognition process again, with a complete control on the number of consonants in the prime.

In this experiment, priming effects were contrasted for words having multi-letter graphemes (one-grapheme targets) with priming effects for matched words without multi-letter graphemes (two-grapheme targets). Both word types were primed by either TL (transposed-letter) primes (i.e., the two letters in the grapheme or two internal letters in words without multi-letter graphemes were transposed, for example, anhtem-ANTHEM or emlbem-EMBLEM) or RL (replacement-letter) primes (i.e., the two letters in question were replaced, for example, ankfem-ANTHEM or emfdem-EMBLEM). As in Experiment 1, the expectation is that disrupting a multi-letter grapheme is less problematic than disrupting two graphemes in the words without multi-letter graphemes. Hence, the words containing a multi-letter grapheme (one-grapheme targets) should produce larger priming effects. Note also, that, as mentioned, the primes and targets in the two target type conditions are matched in terms of the number of consonants maintained in the prime.

Method

Participants. The participants were 56 undergraduate students from the University of Western Ontario who received either course credit or $10 (CDN) for their participation in a set of (unrelated) experiments. All participants were native speakers of English and had normal or corrected-to-normal vision.

Stimuli and Apparatus. The word targets were 96 English words between 6 and 9 letters in length. Forty-eight of the words contained a two-consonant grapheme in the middle and 48 had a two-consonant bigram involving two graphemes. The two word sets were matched on mean frequency (13.3 vs 14.5 per million, respectively, Kucera & Francis, 1967), bigram frequency (2.23 vs 2.36, respectively), N (1.06 vs 1.02, respectively, Coltheart, Davelaar Jonasson & Besner, 1977) and length (7.56 vs 7.58, respectively). They were also matched on the position of the first letter that was to be manipulated (3.50 vs 3.60, respectively).

For each of these word types, two related primes were created. In one, the two letters of interest were transposed (e.g., anhtem-ANTHEM, emlbem-EMBLEM). In the other, those two letters were replaced by letters not contained in the target word (e.g., ankfem, emfdem). Each set of 48 targets was further divided into four subsets for purposes of counterbalancing. One set was presented with their TL primes, a second with their RL primes, a third with unrelated TL primes and a fourth with unrelated RL primes. Primes for these last two conditions were selected by re-pairing primes and targets from within a subset with the restriction that the prime and target share no letters.

Ninety-six nonwords were created by changing one letter of a real word having between 6 and 9 letters. Forty-eight contained a two-letter grapheme and 48 contained a bigram involving two graphemes. Primes for the nonwords were created in the same way as for the words. Because a given participant saw each target only once, in order to successfully counterbalance the assignment of targets to conditions, there were four groups of participants (each group containing 14 individuals).

The experiment was run using DMDX experimental software (Forster & Forster, 2003). Stimuli were presented on a SyncMaster monitor (Model No. 753DF). Presentation was controlled by an IBM-clone Intel Pentium. Stimuli appeared as black characters on a white background. Responses to stimuli were made by pressing one of two <shift> keys on the keyboard.

Procedure. The procedure was the same as in Experiment 1 except that the string of number signs was presented for 550 ms, the primes were presented for 55 ms and there were only 8 practice trials.

<u>Results</u>

Error trials (6.3% of the word trials, 5.0% of the nonword trials) and trials with latencies longer than 1500 ms or less than 250 ms (6.5% of the word trials, 10.6% of the nonword trials) were removed from the latency analyses. For both the word and nonword analyses, 2 (Prime Type: transposed-letter vs replacement-letter) x 2 (Relatedness: related vs unrelated) x 2 (Target Type: one-grapheme vs two-graphemes) x 4 (List) ANOVAs were performed with either subjects (F_1) or items (F_2) as a random factor. Prime Type and Relatedness are within-subject and within-item factors. Target Type is a within-subject and between-item factor. List is a between-subject and between-item factor which was again included as a dummy factor in order to remove variance due to the counterbalancing of stimuli across conditions (Pollatsek & Well, 1995). The mean latencies and error rates from the subject analyses are contained in Table 2.

Word latencies. The only significant main effects were Relatedness ($F_1(1,52) = 46.85$, $MSe = 4368.3$, $p<.001$; $F_2(1,88) = 80.54$, $MSe = 2524.0$, $p<.001$) and Prime Type ($F_1(1,52) = 5.68$, $MSe = 4060.3$, $p<.05$; $F_2(1,88) = 6.25$, $MSe = 3037.8$, $p<.05$). Words were responded to more rapidly following related primes and more rapidly in the TL prime condition. These effects were qualified by a significant Relatedness by Prime Type interaction ($F_1(1,52) = 4.73$, $MSe = 2942.8$, $p<.05$; $F_2(1,88) = 4.17$, $MSe = 3324.7$, $p<.05$), due to the fact that the Relatedness (i.e., priming) effect was larger with TL primes than with RL primes (the transposed-letter prime advantage). None of the interactions involving Target Type approached significance (all Fs < 1.00).

Word errors. The only significant main effects were the Relatedness effect in the item analysis ($F_1(1,52) = 3.40$, $MSe = 0.005$, $p<.08$; $F_2(1,88) = 4.92$, $MSe = 0.005$, $p<.05$) and the Target Type effect in the subject analysis ($F_1(1,52) = 4.25$, $MSe = 0.004$, $p<.05$; $F_2(1,88) = 0.92$, $MSe = 0.034$, $p>.25$). Error rates were 1.3% higher for words following unrelated primes than for words following related primes and 1.3% higher to words containing multi-letter graphemes than to words not containing multi-letter graphemes. None of the interactions were significant (all ps > .10).

Nonword latencies. The only significant main effect was was the effect of Target Type ($F_1(1,52) = 20.94$, $MSe = 3129.2$, $p<.001$; $F_2(1,88) = 4.97$, $MSe = 12170.6$, $p<.05$). Nonwords containing multi-letter graphemes were rejected 25 ms faster than nonwords not containing multi-letter graphemes. The only other significant effect was the Target Type by Relatedness interaction in the item analysis ($F_1(1,52) = 1.65$, $MSe = 3360.3$, $p>.20$; $F_2(1,88) = 4.39$, $MSe = 4217.4$, $p<.05$). Nonwords with multi-letter graphemes showed a 7 ms negative priming effect whereas nonwords without multi-letter graphemes showed a 7 ms positive priming effect. None of the other interactions were significant (all ps>.10).

Nonword errors. As in the latency data, the only main effect that was significant was the main effect of Target Type, although only in the subject analysis ($F_1(1,52) = 9.09$, $MSe = 0.005$, $p<.01$; $F_2(1,88) = 1.66$, $MSe = 0.022$, $p>.20$). Nonwords containing multi-letter graphemes had an error rate 1.9% less than nonwords not containing multi-letter graphemes. None of the other effects approached significance (all ps>.25).

Discussion

As in Experiment 1, there is little in these data supporting the idea that grapheme units are important in the word recognition process. That is, it doesn't seem to matter whether the multi-letter grapheme is transposed or replaced, the resulting prime produced virtually the same amount of priming as the same manipulation done to two adjacent letters that represent separate graphemes.

Experiment 3

As in Experiment 1, although there was no statistical evidence supporting the idea that the priming patterns were different in the one- and two-grapheme conditions, the data pattern in Experiment 2 was not completely inconsistent with that possibility. That is, the priming effects were slightly larger for the multi-letter grapheme words than for the other words in both the TL (6 ms) and RL (3 ms) conditions. Thus, the question again emerges as to whether these effects might be real, albeit small. In Experiment 3, we attempted to increase the potential for observing the effects we were looking for. Experiments 1 and 2 were done in English. English has a fairly deep orthography and one could certainly argue that the nature of the representational units for English readers is not likely to be strongly shaped by phonology. In contrast, Spanish has a fairly shallow orthography. Hence, it seems reasonable that the nature of the orthographic representations would be more strongly shaped by phonology in Spanish and, therefore, one might be able to find effects of the sort being examined here in experiments using Spanish words. [4]

As it turns out, there are only a few multi-letter graphemes in Spanish. Leaving aside the graphemes “rr” and “ll” (which contain repeated letters), in Spanish, there are only two multi-letter graphemes: CH and QU. The focus of Experiments 3 and 4 is the Spanish grapheme CH which is pronounced as the phoneme /J/.

In both of these experiments, the manipulation was similar to that in Experiment 2. There were TL and RL manipulations involving both words with a CH grapheme (one-grapheme targets) and matched words without a multi-letter grapheme (two-grapheme targets). The main difference between the manipulation in Experiment 3 and that in Experiment 2 was that no unrelated control conditions were used. Thus, the specific prediction is slightly different as well. As noted previously, both removing and transposing the letters in a multi-letter grapheme should be less damaging than similar manipulations done to two adjacent letters that create two graphemes. Therefore, one would expect shorter latencies in both the TL and RL prime conditions for words containing a multi-letter grapheme than for words that do not.[5]

Following from the argument presented in footnote 3, the contrast between the two related prime conditions (i.e., the RL-TL difference) as a function of target type may also be of interest. In the TL prime conditions, all the target's graphemes are maintained in the primes for two-grapheme stimuli (serceto for SECRETO) but not in the primes for the one-grapheme stimuli (mehcero for MECHERO). Such is not the case in the RL prime condition (i.e., senseto and mebvero). Therefore, one could construct an argument that the two-grapheme condition targets might have an advantage over the one-grapheme targets when using TL, but not RL, primes. If this argument were valid, one would, therefore, expect a larger TL-RL difference for two-grapheme targets than for one-grapheme targets.

Method

Participants. The participants were 28 undergraduate students from the Universitat de València. All participants were native speakers of Spanish. All had normal or corrected-to-normal vision.

Materials. The word targets were 128 Spanish words that were six to ten letters in length (mean number of letters: 7.7). Sixty-four of these words (the one-grapheme targets) had the grapheme CH in an internal position of the word (second or third syllable, e.g., MECHERO-the Spanish word for lighter). The other sixty-four words (two-grapheme targets) had two adjacent consonants in internal positions of the word and those consonants formed two graphemes (e.g., SECRETO-the Spanish word for secret). Word frequency was controlled across one-grapheme and two-grapheme target words (mean frequency per one million: 4.6 and 4.9 for one-grapheme and two-grapheme target words, respectively, in the Spanish database, Davis & Perea, 2005). The targets were presented in uppercase and were preceded by primes in lowercase that were 1) the same as the target except for a transposition of either the two grapheme constituents or the two adjacent consonants (mehcero-MECHERO or serceto-SECRETO, the TL condition) or 2) the same as the target except for the replacement of the two letters of interest by two consonants with the same word shape (mebvero-MECHERO or sensato-SECRETO, the RL condition). The primes were always nonwords. Bigram frequencies for the TL and RL primes were matched (mean bigram frequency 1.8 and 1.8, respectively, $p>.50$). An additional set of 128 nonwords was also selected because the task was lexical decision (64 containing a CH and 64 not containing a CH or any other multi-letter grapheme). The manipulation for the nonword targets was the same as that for the word targets.

Two lists of materials were constructed so that each target appeared once in each list. In one list, half the targets were primed by TL primes and half were primed by RL primes. In the other list, targets were assigned to the opposite prime conditions. Half of the participants were presented with each list.

Procedure. The procedure was the same as in Experiment 1.

Results

Incorrect responses (5.6 % for word targets and 9.6% for nonword targets) and latencies less than 250 ms or greater than 1500 ms (3.1%) were excluded from the latency analysis. The mean latencies for correct responses and the error percentages are presented in Table 3. Subject and item ANOVAs based on both subject and item correct response latencies and error rates were conducted, based on a 2 (Target Type: one-grapheme vs two-graphemes) x 2 (Prime Type: transposed-letter vs replacement-letter) x 2 (List) design. Prime Type is a within-subject and within-item factor. Target Type is a within-subject and between-item factor. List is a between-subject and between-items factor. The mean latencies and error rates from the subject analyses are contained in Table 3.

Word latencies and errors. Words preceded by a TL prime were responded to 13 ms faster than the targets preceded by an RL prime, $F_1(1, 26) = 6.16$, $MSe = 740.3$, $p<.025$, $F_2(1, 124) = 5.08$, $MSe = 1506.8$, $p<.025$. This transposed-letter prime advantage was similar for one-grapheme and two-nongrapheme targets, as indicated by the lack of an interaction between Prime Type and Target Type (both *p*s>.15). Most importantly, there were no significant effect of Target Type (both *p*s>.15). The ANOVA on the error data did not reveal any significant effects (all *p*s>.15).

Nonword latencies and errors. None of the effects approached significance in the ANOVAs on the nonword data (all *p*s>.15).

Discussion

The results of Experiment 3 (in Spanish) support the main finding and conclusion of Experiment 2 (in English). Neither RL nor TL primes conveyed any advantage on words with a multi-letter grapheme over words without a multi-letter grapheme. Note also that the TL - RL difference did not vary as a function of whether the letters involved form a multi-letter grapheme or not. These results provide additional support for the idea that adjacent letters forming a single grapheme are processed no differently than adjacent letters which involve two graphemes.

Experiment 4

In Experiments 2 and 3, both the TL and RL manipulations were designed in a way that maintained the integrity of the multi-letter grapheme (as was also true in the one-grapheme condition in Experiment 1). That is, the two letters making up the multi-letter grapheme were either removed together or both were maintained with their order reversed. The expectation was that doing so would produce a prime that would be superior to the prime in the two-grapheme condition due to the fact that the primes in the two-grapheme conditions in all experiments disturbed two graphemes. As noted, none of these manipulations produced the expected result (i.e., the primes were equally effective in the one- and two-grapheme conditions). In Experiment 4, a different approach was taken. In this experiment, the main manipulation was designed to produce primes that would be less effective for the one-grapheme words than for the two-grapheme words.

In Experiment 4 there were two separate manipulations. In the first and more central manipulation, there were again TL and RL primes, however, the transposition involved the second letter of the grapheme and the next letter in the word (e.g., mecehro-MECHERO or menedro-MECHERO) in the one-grapheme words. As in Experiment 3, the impact of these primes was compared to the impact of similar manipulations for two-grapheme words, that is, words not having a multi-letter grapheme (e.g., secerto-SECRETO or senesto-SECRETO). Because the two-grapheme words, as in Experiments 2 and 3, involved the transposition or replacement of two graphemes, the pattern they produce in Experiment 4 should be comparable to the patterns they produced in Experiments 2 and 3 (i.e., a transposed-letter prime advantage). In contrast, for the one-grapheme words, there is a clear difference between these manipulations and the TL and RL manipulations in previous experiments (manipulations that were, as noted, intended to manitain the integrity of the multi-letter grapheme). Specifically, in Experiment 4, both TL and RL primes not only eliminated the two-letter grapheme sequence, they also added 2 incorrect graphemes (i.e., in mecehro, the “c” and the ‘h’, in menedro, the “n” and the “d”). The expectation, therefore, is that the TL and RL primes should not differ in effectiveness and they should be less effective than in the prior experiments. That is, unlike in Experiments 2 and 3, they should now be less effective than the RL and TL primes in the two-grapheme condition, yielding a

Target Type main effect.

In addition, in Experiment 4 we include two new conditions, one in which the prime was the same as the target except for the deletion of the second constituent of the grapheme (mecero-MECHERO, deleted-letter, “DL” condition), and one in which the two-letter grapheme was replaced by a single letter (menero-MECHERO, substituted-letter, “SL” condition). There were also parallel conditions involving words not containing multi-letter graphemes (e.g., seceto-SECRETO or seneto-SECRETO). These conditions were included essentially to address a potential alternative account of the results in the other conditions. That is, if the TL condition described above does not produce longer latencies for one-grapheme targets, one possible reason is that the letter from the grapheme that remains in position (e.g., “c” in mecehro-MECHERO) may have some ability to partially activate the relevant multi-letter grapheme representational unit. If so, given that that first letter is also contained in the DL condition with the one-grapheme words (i.e., mecero-MECHERO), one would expect DL primes to be effective primes for those words, leading to a larger DL-SL difference for words having multi-letter graphemes.

<u>Method</u>

Participants. The participants were 44 undergraduate students from the Universitat de València. All of them had normal or corrected-to-normal vision and were native speakers of Spanish.

Materials. The word and nonword targets were the same as in Experiment 3. The targets were presented in uppercase and were preceded by primes in lowercase that were the same as the target 1) except for a transposition of the second letter of the grapheme and the following letter (mecehro-MECHERO, TL condition), 2) except for the replacement of the transposed letters (menedro-MECHERO, RL condition), 3) except for the deletion of the second letter of the grapheme (mecero-MECHERO, DL condition), and 4) except for the replacement of the grapheme by a single letter (menero-MECHERO, SL condition). These four conditions were mimicked for words like SECRETO having no multi-letter graphemes. The primes were always nonwords and bigram frequencies between conditions did not differ significantly (all *p*s>.50). The priming manipulations for the nonword targets were the same as that for the word targets.

The primes were always nonwords and bigram frequencies between conditions for the word target primes did not differ significantly (all *p*s>.50). Four lists of materials were constructed to counterbalance the items, so that each target appeared once in each list. One quarter of the participants were presented with each list.

Procedure. The procedure was the same as in Experiment 1.

Results

Incorrect responses (5.9% for word targets and 8.8% for nonword targets) and latencies less than 250 ms or greater than 1500 ms (1.6% for word targets) were excluded from the latency analysis. In one analysis, ANOVAs involving both subject and item response latencies and error rates were conducted based on a 2 (Target Type: one-grapheme vs two-grapheme words) x 2 (Prime Type: transposition vs replacement,) x 4 (List) design. In a second analysis, ANOVAs involving both subject and item response latencies and error rates were conducted based on a 2 (Target Type: on-grapheme vs two-grapheme words) x 2 (Prime Type: deletion, substitution,) x 4 (List) design. In both analyses, Prime Type is a within-subject and within-item factor, Target Type is a within-subject and between-item factor and List is a between-subject and between-item factor. The mean latencies and error rates from the subject analyses are presented in Table 4.

Transposed- versus Replacement-letter effects

Word latencies and errors. Words preceded by TL primes were responded to 17 ms faster than words preceded by RL primes, $F_1(1, 40) = 13.19$, $MSe = 933.9$, $p<.001$, $F_2(1, 120) = 10.21$, $MSe = 2155.1$, $p<.005$. In addition, words without multi-letter graphemes were responded to 15 ms slower than words with a CH-grapheme in the analysis by subjects, $F_1(1, 40) = 10.51$, $MSe = 905.1$, $p<.005$, $F_2>1$. There was no interaction. No significant effects were found in the error data, (all *p*s>.15).

Nonword latencies and errors. There was an effect of Nonword Type, $F_1(1, 40) = 8.24$, $MSe = 1271.3$, $p<.01$, $F_2(1, 120) = 4.36$, $MSe = 5854.3$, $p<.05$, due to the fact that nonwords that contained a CH grapheme were responded to 15 ms slower than nonwords without a multi-letter grapheme. No other effects were significant in either the latency or error ANOVAs (all *p*s >.15).

Deleted- versus Substituted-letter effects

Word latencies and errors. The ANOVA on the latency data showed an effect of Target Type in the subject analysis, $F_1(1, 40) = 16.42$, $MSe = 939.4$, $p<.001$, $F_2 <1$: words without a multi-letter grapheme were responded 19 ms slower than words with a CH-grapheme. No other effects were significant in either the latency or error ANOVAs (all *p*s >.15).

Nonword latencies and errors. There were no significant effects in the nonword analyses, (all *p*s >.15).

Discussion

The results of Experiment 4 show that the TL-RL contrast was remarkably similar in size when the prime manipulation involved splitting a multi-letter grapheme (CH) versus when the prime manipulation involved splitting two letters that do not form a grapheme (e.g., CR). With respect to the main prediction, that the primes will be more effective for two-grapheme targets than for one-grapheme targets, the data actually showed exactly the opposite pattern. In addition, the DL-SL contrast also showed no effect for the CH targets. This final result provides no support for the idea that the first letter in a multi-letter grapheme may be able to partially activate a sublexical representational unit for that grapheme. Taken together (and along with the results of the previous experiments), the results of Experiment 4 support the conclusion that units for (multi-letter) graphemes have no special status and, therefore, those units are not the perceptual units driving the word recognition process.

General Discussion

The main goal of these experiments was to investigate the idea that representational units for (multi-letter) graphemes drive the word recognition process. To that end, a number of priming conditions were created involving primes that disturbed the two letters in a multi-letter grapheme as well as two adjacent letters either in the same words or in words not containing a multi-letter grapheme. In Experiments 1, 2 and 3, more priming was expected when the letters in multi-letter graphemes were disturbed, whereas in the TL and RL prime conditions in Experiment 4, it was expected that the primes would be less potent when using targets containing multi-letter graphemes. In virtually all of the experiments, however, the effects were virtually the same when the constituents of a multi-letter grapheme were disturbed as when two letters that did not form a multi-letter grapheme were disturbed. Further, results in Experiment 4 showed that: a) there was still an TL prime advantage when the second letter in a multi-letter grapheme was transposed with the subsequent letter in spite of the fact that the TL and RL manipulations should have been equally destructive to the multi-letter grapheme and b) a prime containing the first letter of a multi-letter grapheme (the DL condition) did not produce significantly shorter latencies than a prime containing a letter that was not a constituent of the multi-letter grapheme (the SL condition) suggesting that single letters do not have the ability to activate multi-letter grapheme units.

The present findings are, therefore, entirely consistent with the argument that multi-letter graphemes are not represented as units in the visual word recognition system at a level of processing relevant to initial visual word idenfication. As noted previously, readers do recognize that the pronunciation of a multi-letter grapheme is not the concatenation of the pronunciations of its constituant letters which means that there must be representational units for the phonemes of multi-letter graphemes somewhere in the system. The phonological computation leading to activation of these phonemes may, of course, be directly linked to early orthographic activation processes, however, that fact does not imply that those units play any role in the normal word recognition process.

So, what then is the nature of the sublexical units that drive the word recognition process? The most obvious answer, and one consistent with most current models of word recognition, is that they are letter units. However, the present data can not be regarded as providing incontrovertible proof of this specific conclusion. That is, for example, the present results are not at all incompatible with the proposal, incorporated in open-bigram models (e.g., Dehaene et al., 2005; Grainger & van Heuven, 2003; Grainger et al., 2006; Schoonbaert & Grainger, 2004; Whitney, 2001, 2004), that word units are activated by bigram units. In fact, models of this sort would be very consistent with the present findings since, by their nature, they make no distinction between the bigrams forming a grapheme and all other bigrams. Similarly, the present data would not necessarily rule out accounts based on larger sublexical units like vocalic center groups (Smith & Spoehr, 1974; Spoehr & Smith, 1975), BOSSes (Taft 1979) or rimes (Treiman et al., 1995) as the present experiments were not specifically designed to test these alternative possibilities.

What the present results also do is to point to the conclusion that the prior results supporting the existence of representational units for multi-letter graphemes were more likely effects of phonology. Indeed, many of those experiments involved processes far removed from the lexical activation process involved in normal reading, e.g., Rapp and colleagues' spelling experiments (e.g., Buchwald & Rapp, 2004; Tainturier & Rapp, 2004) and Rey et al.'s (1998) luminance incrementing experiment. Others expressly required the activation of phonological information because the task was a naming task (Rastle & Coltheart, 1998; Rey et al., 1998; Rey & Schiller, 2005). The two exceptions are the letter detection task used by Marinus and de Jong (2011) and Rey et al. (2000) and the mixed-case lexical decision task used by Havelka and Frankish (2010). Performance in both tasks likely involves the lexical activation processes involved in reading and in neither task is the use of phonology required.

What is true about both tasks, however, is that performance would certainly be aided by the use of phonology. In a letter detection task, when presented with the letter H as a target, it would be quite useful to simultaneously search the visual stimulus for that letter and the phonological code generated by that stimulus for the phoneme /h/. When that letter is in a multi-letter grapheme like CH, only one of those searches would be successful, slowing down detection latency in comparison to the case when the both the letter H and the grapheme /h/ exist in the word (e.g., OVERHANG). The only result inconsistent with this analysis is Rey et al.'s Experiment 2 result which, as noted, could not be replicated by Brand et al. (2007).

In the mixed case lexical decision task used by Havelka and Frankish (2010), phonological codes may also play an important role in a participant's processing strategy. Simuli like cOaSt do not have a familiar visual form and, as Mayall et al.

(1997) have noted, can lead to some rather unusual grouping processes causing the normal sublexical processes to unfold somewhat slowly if at all. If a phonological code could be derived and compared against lexical representations in a phonological lexicon, some of the delay caused by the unfamiliar visual representation could be overcome. If this is what is done, it would seem like it would be easier to group the two letters of a grapheme together in order to derive that phonological code if they are the same case (e.g., OA) than if they are different cases (e.g., Oa), producing the same case advantage that Havelka and Frankish reported.

Findings of No Difference

One aspect of the present data that should be mentioned is that, in virtually all cases, what the results showed was equivalent effects in two key conditions. That is, there were equivalent priming effects in Experiment 1, there were equivalent priming effects for the two word types in both the RL and TL conditions in Experiment 2 and there were essentially equivalent latencies and TL advantages for the two word types in Experiments 3 and 4. Such a situation, of course, is far from ideal. It would have been better to have been able to base our conclusions on a set of findings showing significant differences between conditions. Therefore, one may be tempted to feel that the strength of the support for our conclusion that is provided by the present results is less than one would want. To a large degree, however, these concerns are mitigated by a number of considerations.

First, in Experiments 1 and 2 and, to some extent in Experiments 3 and 4, the observed equivalency was not between two mean latencies but between the sizes of two effects with the effects themselves (as well as the TL-RL difference in Experiment 2) being highly significant. Therefore, there does not seem to have been any lack of power in our analyses. Second, while a number of factors could cause a single difference to not be significant, the lack of a difference across a set of 4 experiments, carried out in three different labs using two languages, would appear to rule out a simple explanation of this sort. Both of these facts speak to what Frick (1995) refers to as “the good effort” criterion that needs to be satisfied before one accepts a null hupothesis. Third, the issue in question here was whether there was any role for units representing multi-letter graphemes in the word recognition process. The conclusion we have drawn is that there is not. Something’s lack of an impact can only be demonstrated by showing that the system does not operate in the fashion expected if that thing did have an impact. Therefore, a demonstration that something does not have an impact, virtually by definition, would require a set of findings like those reported here. Indeed, as Rouder, Speckman, Sun, Morey and Iverson (2009) have argued, identifying invariance is critical for theoretical advancement (see Rouder et al., 2009, for a number of examples in psychology and other sciences).

The final consideration is statistical. Because the standard way of analyzing data in psychology (i.e., null hypothesis significant testing) can lead to a situation like that produced here, diminishing the ability of researchers to make strong conclusions when the null hypothesis appears to be true, new statistical methods have recently been developed, methods based on Bayesian analysis (e.g., see Gallistel, 2009; Masson, 2011; Rouder et al., 2009; Wagenmakers, 2007; Wagenmakers, Ratcliff, Gómez & Iverson, 2004). One method is to employ parametric bootstrapping simulations (Wagenmakers et al., 2004), in which simulated data are generated on the basis of two hypotheses (the null hypothesis and the alternative hypothesis) and a likelihood ratio of the two scenarios is obtained (e.g., see Perea, Gómez & Fraga, 2010). A simpler alternative, which does not require complex methods (and is the one adopted here), is to compute the probability of the null hypothesis being true, given the obtained data, $p(H_0|D)$ (Wagenmakers, 2007; see Masson, 2011, for examples of how to compute this index). Positive evidence that the null hypothesis is true is obtained when this probability value is above .75. Strong evidence is obtained with probability values above .90 (Raftery, 1995; see also Masson, 2011).

The obtained the $p(H_0|D)$ values in the present experiments for the subject and item analyses were .86 and .88 in Experiment 1 and .87 and .91 in Experiment 2 for the relevant interaction (Number of Graphemes Changed by Relatedness in Experiment 1, Target Type by Relatedness in Experiment 2). In Experiment 3, the $p(H_0|D)$ values for the relevant main effect (Target Type) were .84 and .91. The values for the Target Type main effect in Experiment 4 were .04 and .84, with the value in the subject analysis implying that the null hypothesis is wrong. As noted, however, with respect to the issues under investigation, the main effect in Experiment 4 went in the wrong direction (i.e., multi-letter grapheme words had shorter latencies than words without a multi-letter grapheme). This analysis, therefore, provides additional support for the conclusion that multi-letter graphemes are not represented as units in the reading system at a level of processing relevant to initial visual word idenfication. [6]

Simulations

The evidence from all four experiments reported here indicates that priming effects are equivalent for primes in which a multi-letter grapheme has been disturbed and primes in which the disturbed letter pair creates two graphemes. To this point, we have assumed that this evidence would be consistent with letter-based models of visual word identification. To examine this assumption further, we conducted simulations of the present data. For this purpose, we used the spatial coding model, which has been shown to accommodate a very broad range of masked form priming data (Davis, 2010). The model’s default vocabulary contains 30,605 English words, and thus we were able to use the model to simulate the results from Experiment 1 and 2 (i.e., the English-language experiments that we report here). The testing procedure and parameters were identical to those in Davis (2010), except that the mismatch inhibition parameter was set to zero (a setting of .04, as in Davis, 2010, would result in an identical pattern of predictions, but smaller predicted priming effects overall). Both simulations produced a good fit to the observed data. Figure 2 shows the correspondence between the data and model predictions for Experiment 1. The predicted priming effects for one- and two-grapheme conditions were 17.0 and 18.4 cycles, respectively, compared with observed priming effects of 17 ms and 20 ms (the parameter settings used by Davis, 2010, are scaled so that priming effects in cycles can be compared directly with the effects observed in ms). The interaction of Prime Type and Number of Graphemes Changed was not significant in the simulation data (p = .18). Figure 3 shows the correspondence between the data and model predictions for Experiment 2. The absolute magnitude of the priming effects was slightly smaller in the simulation than in the data, but the pattern of priming effects across conditions was identical in model and data (r=0.99996).

The results of these simulations confirm our expectation that the observed experimental data are consistent with letter-based models of visual word recognition. These simulations do not, of course, demonstrate that Davis's (2010) model is the only model that can account for these data nor even that it provides the optimal account. Open-bigram models may do a good job as well. In fact, it is not impossible that even models incorporating grapheme units could be made to account for the present data if system parameters were selected judiciously (i.e., if the weightings were set so that the impact of those units was quite small). Therefore, what the simulations provide is really an existence proof for the viability of a model based completely on the assumption that the only sublexical units required for modelling word recognition are letter units.

Vowels and Consonants

As previously noted, the multi-letter grapheme words in Experiment 1 were the only stimuli used here that involved multi-vowel graphemes. The reason, as discussed, is that Experiments 2, 3 and 4 all involved transpositions of letters and that primes involving vowel transpositions are no more effective primes than replacement letter primes (i.e., they show no transposed-letter priming advantage; Lupker, Perea & Davis, 2008; Perea & Lupker, 2003; 2004). This fact is true even when the transposed letters are not adjacent and, thus, do not form a grapheme (e.g., caniso-CASINO versus cisano-CASINO). Therefore, this lack of a transposed-letter priming advantage for vowel transpositions can not be due to the fact that those transpositions break up graphemes. In any case, the implication is that the conclusions reached here are much better supported when considering multi-consonant graphemes than multi-vowel graphemes.

As noted, at least some of the research discussed earlier specifically investigated multi-vowel graphemes, for example, Marinus and de Jong (2011). In their experiments, as in the experiments of Rey and colleagues (Rey et al., 1998; 2000), Marinus and de Jong demonstrated that there is greater difficulty finding a letter when it is part of a multi-letter grapheme than when it isn't. As noted, this type of finding can be explained in terms of a parallel phonologically-based search. What is interesting, however, is that Marinus and de Jong found the same effects with dylexics, readers who are poor at generating phonology and, hence, presumably less likely to use such a phonologically-based search strategy. Therefore, the question of whether the present conclusions can be fully extended to multi-vowel graphemes is one that would benefit from further research.

In summary, the masked priming experiments reported in the present article provided multiple opportunities to detect evidence of the influence of multi-letter graphemes. None of these experiments detected any evidence for such an influence. As such, it would appear that SOLAR, SERIOL, Open Bigram, Overlap and other similar letter-input models are able to capture the pattern of "prime-target" similarity reported in the present research. Thus, our data provide good evidence that multi-letter graphemes are not represented as basic perceptual coding units in reading, a conclusion that is compatible with many of the letter coding schemes in recent models of visual word recognition.

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Authors Note

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Correspondence concerning this article should be addressed to: Steve Lupker, Department of Psychology, University of Western Ontario, London, Ontario, N6A 5C2, Canada (e-mail: lupker@uwo.ca).

Footnotes

[1] Over the past decades, there have been a number of models proposing multi-letter representational units. For example, almost 40 years ago, Smith and Spoehr (1974) and Spoehr and Smith (1975) proposed a theory involving units representing "vocalic center groups", units that code various consonant-vowel and vowel-consonant combinations. A few years later, Taft (1979) proposed that there are units representing basic orthographic syllable structures (or BOSSes), subsequently extending this idea with the proposal that there are units representing the body of the BOSS (the BOB, Taft, 1992). Treiman and colleagues (Treiman & Chafetz, 1987; Treiman, Mullennix, Bijeljac-Babic & Richmond-Welty, 1995; Treiman & Zukowski, 1988) have suggested that there may be units corresponding to word onsets and rimes. Note again that none of these models was based on the idea of representational units for graphemes either.

[2] The masked priming paradigm is, of course, not completely immune from the impact of phonology (Ferrand & Grainger, 1993; 1994). For example, Ferrand and Grainger (1994) have shown that pseudohomophone primes can facilitate lexical decision making slightly more than orthographic control primes for low frequency targets when the prime duration is 50 ms, a duration that is essentially the same as those used here. What's more relevant, however, is that these effects are, presumably, not due to the recruitment of phonological information to aid in response production but rather are due to the normal processes involved in word recognition. Therefore, any evidence for the impact of grapheme units in experiments of the sort reported here will need to be explained by models of word recognition, even if the effects ultimately are determined to be phonological in nature.

[3] Due to the fact that all of the graphemes are maintained in the transposed-letter primes in the two-grapheme condition (i.e., emlbem-EMBLEM) but not in the one-grapheme condition (i.e., anhtem-ANTHEM), one could make the counter prediction, that the two-grapheme condition should actually produce more (or at least equivalent) priming. Such would not be the case, however, when using replacement-letter primes. The fact that the data patterns turned out to be the same in the transposed-letter and replacement-letter prime conditions removes this concern. The authors would like to thank Carol Whitney for bringing this issue to our attention.

[4] One could make the counter argument that, due to the fact that English has many more multi-letter graphemes than Spanish, it would be more likely to observe the impact of multi-letter graphemes in English than in Spanish. Although we don't agree with this argument, in the end, it becomes immaterial which language might be optimal for observing these effects since the data patterns were virtually the same in the two languages.

[5] The same contrast can, of course, be carried out based on the data from Experiment 2. The results in Experiment 2 provide no support for the idea that it is easier to respond to multi-letter grapheme words following RL or TL primes than it is to respond to words without multi-letter graphemes. Indeed, in both cases, the small difference goes in the opposite direction. Experiments 3 and 4, however, provide a much better examination of this issue as they are based on a larger set of words and, as we have argued, in the language used (Spanish), it is more likely that the nature of a reader's orthographic representations would be shaped by phonology.

[6] The corresponding $p(H_0|D)$ values for the subject and item analyses for the parallel interactions in Experiments 3 and 4 (Target Type by Prime Type) are .84 and .92 (Experiment 3), and .82 and .88 (Experiment 4).

Table 1

Mean lexical decision times in ms and percentage of errors (in parentheses) for word and nonword targets in Experiment 1

	One Grapheme	*Two Graphemes*
Rel	536 (4.0)	541 (6.0)
Unrel	556 (6.0)	558 (6.0)
Priming	20 (2.0)	17 (0.0)

Table 2

Mean lexical decision times in ms and percentage of errors (in parentheses) for word and nonword targets in Experiment 2

	Transposed-Letter		*Replacement-Letter*	
	One *Grapheme*	*Two Grapheme*	*One Grapheme*	*Two Grapheme*
Word data				
Rel	710 (6.7)	701 (4.7)	733 (6.5)	729 (7.0)
Unrel	767 (8.7)	752 (6.2)	766 (7.9)	759 (7.0)
Priming	57 (2.0)	51 (1.5)	33 (1.4)	30 (0.0)
Nonword data				
Rel	819 (5.4)	840 (6.9)	824 (4.2)	837 (7.1)
Unrel	828 (5.2)	851 (6.4)	801 (3.8)	840 (6.2)
Priming	9 (-0.2)	11 (-0.5)	-23 (-0.4)	3 (-0.9)

Table 3

Mean lexical decision times in ms and percentage of errors (in parentheses) for word and nonword targets in Experiments 3

	CH (One Grapheme)	*Two Grapheme*
Word data		
TL	692 (5.9)	694 (5.0)
RL	706 (5.1)	706 (6.4)
TL effect	14 (-0.8)	12 (1.4)
Nonword data		
TL	833 (11.2)	849 (10.8)
RL	837 (10.0)	843 (10.9)
TL effect	3 (-1.1)	- 7 (0.1)

CH=target containing a CH grapheme, TL= transposed-letter condition, RL= replacement-letter condition

Table 4

Mean lexical decision times in ms and percentage of errors (in parentheses) for word and nonword targets in Experiments 4

	TL	RL	*TL effect*	DL	SL	*DL effect*
Word data						
CH (One Grapheme)	636 (5.4)	656 (6.8)	20 (1.4)	647 (4.8)	643 (5.0)	-4 (0.2)
Two Grapheme	654 (5.4)	668 (6.1)	14 (0.7)	661 (6.6)	667 (4.2)	6 (-2.4)
Nonword data						
CH (One Grapheme)	772 (8.0)	774 (6.6)	2 (-1.4)	791 (7.5)	776 (7.8)	-16 (0.3)
Two Grapheme	787 (10.2)	790 (7.6)	3 (-2.6)	781 (6.9)	781 (5.4)	0 (-1.6)

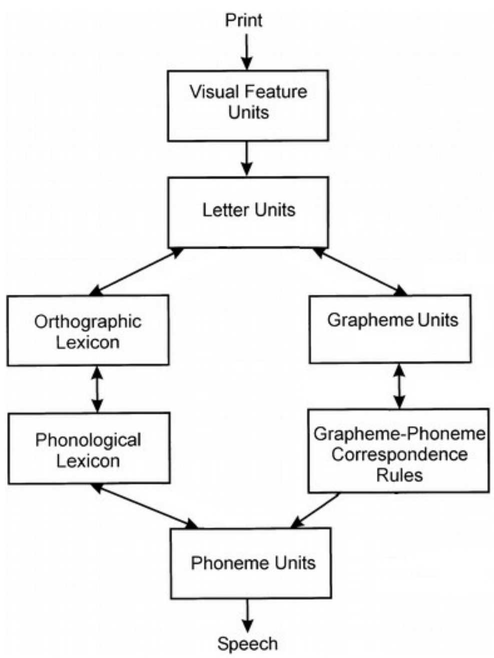
CH=target containing a CH grapheme, TL=transposed-letter condition, RL=replacement-letter condition, TL effect= difference between RL and TL conditions, DL=deleted-letter condition, SL=substituted-letter condition, DL effect=difference between DL and SL conditions.

Figure Captions

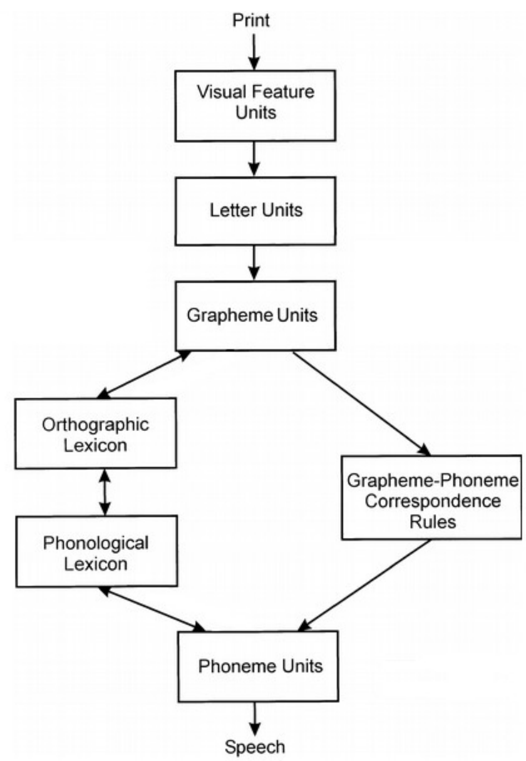
Figure 1: Two possible versions of a dual-route model of visual word recognition. (a) a letter-input model, in which the common input to both routes comes from a level of (abstract) letter units, and (b) a grapheme-input model, in which the common input to both routes comes from a level of grapheme units. Both models assume the existence of grapheme representations, but in the letter-input model these units are assumed to be specific to the non-lexical, grapheme-phoneme conversion route.

Figure 2: Observed mean decision latency for the prime conditions in Experiment 1 and corresponding mean decision latencies in Simulation 1.

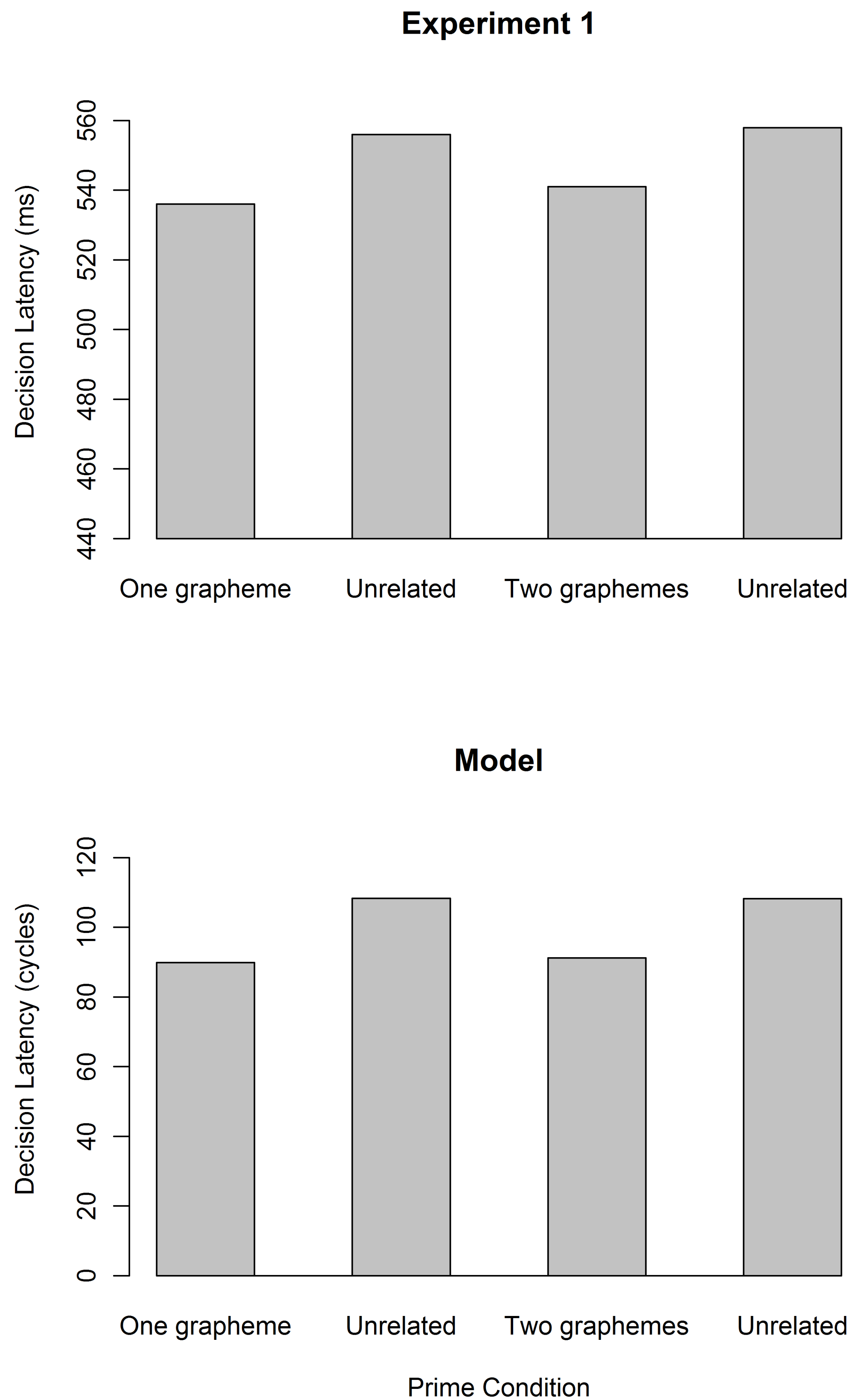
Figure 3: Observed priming effects for the prime conditions in Experiment 2 and corresponding predicted priming effects in Simulation 2.

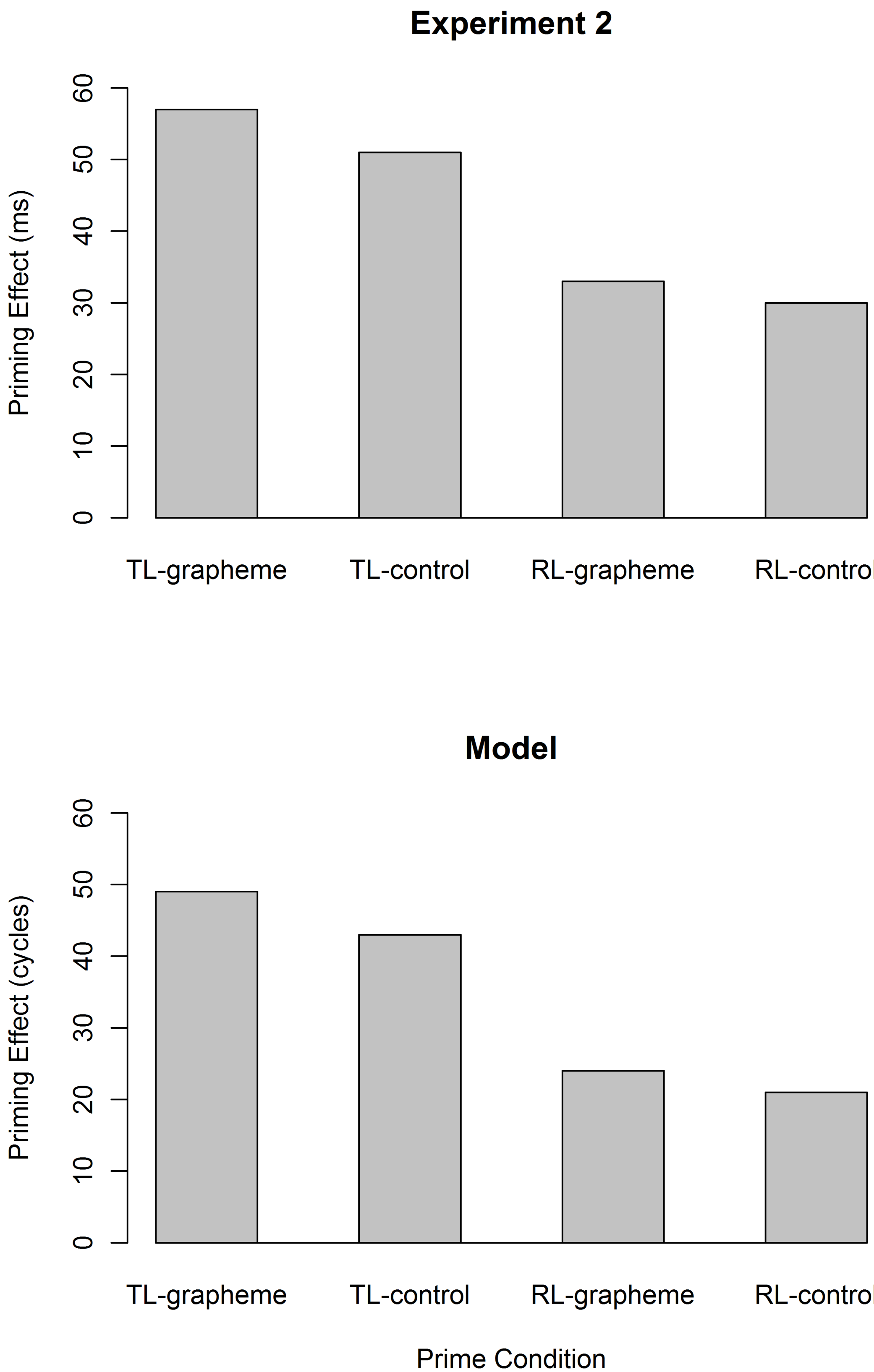


(a) A letter-input dual-route model



(b) A grapheme-input dual-route model


Experiment 1
Decision Latency (ms)
440
460
480
500
520
540
560
One grapheme
Unrelated
Two graphemes
Unrelated
Model
Decision Latency (cycles)
0
20
40
60
80
100
120
One grapheme
Unrelated
Two graphemes
Unrelated
Prime Condition


Experiment 2
Priming Effect (ms)
0
10
20
30
40
50
60
TL-grapheme
TL-control
RL-grapheme
RL-control
Model
Priming Effect (cycles)
0
10
20
30
40
50
60
TL-grapheme
TL-control
RL-grapheme
RL-control
Prime Condition

Appendix

Stimuli in Experiment 1

Words			Nonwords	
Target	One Grapheme Prime	Two Grapheme Prime	Target	Prime
AMOUNT	amxxnt	axxunt	AFOURT	afxxrt
BLOUSE	blxxse	bloxxe	BROUYE	brxxye
BLEACH	blxxch	bxxach	BREASH	brxxsh
BREAST	brxxst	brexxt	BLEACT	blxxct
BREATH	brxxth	bxxath	BLEAPH	blxxph
CHOICE	chxxce	choxxe	CROIME	crxxme
CLOUDY	clxxdy	cxxudy	CROUSY	crxxsy
CREAMY	crxxmy	crexxy	CLEAGY	clxxgy
CREASE	crxxse	cxxase	CHEAME	chxxme
DREAMT	drxxmt	drexxt	DOEANT	doxxnt
FLAUNT	flxxnt	fxxunt	FRAUST	frxxst
GREASY	grxxsy	grexxy	GWEABY	gwxxby
GROUND	grxxnd	gxxund	GLOURD	glxxrd
GROUSE	grxxse	groxxe	GLOUME	glxxme
PLAYER	plxxer	pxxyer	SLAYEN	slxxen
PLEASE	plxxse	plexxe	PHEAVE	phxxve
PRAISE	prxxse	pxxise	PLAIVE	plxxve
PREACH	prxxch	pxxach	TREAGH	trxxgh
PRIEST	prxxst	prixxt	PLIERT	plxxrt
QUAINT	quxxnt	quaxxt	QUAIRT	quxxrt
SHIELD	shxxld	shixxd	SKIEND	skxxnd
SNEAKY	snxxky	sxxaky	SPEANY	spxxny
SPOUSE	spxxse	spoxxe	STOUWE	stxxwe
STEADY	stxxdy	sxxady	SWEAGY	swxxgy
STEAMY	stxxmy	stexxy	SPEADY	spxxdy
SWEATY	swxxty	sxxaty	STEAVY	stxxvy
TRAUMA	trxxma	traxxa	TWAULA	twxxla
TREATY	trxxty	txxaty	TWEAFY	twxxfy
UNEASY	unxxsy	unexxy	UREATY	urxxty
WREATH	wrxxth	wxxath	WHEASH	whxxsh
BOILER	bxxler	boxxer	COIPER	coxxer
BOUNCE	bxxnce	boxxce	DOURCE	doxxce
BOUNTY	bxxnty	boxxty	GOUSTY	goxxty
COURSE	cxxrse	coxxse	FOUTSE	foxxse

FAULTY	fxxlty	faxxty	NAUPTY	naxxty
LAUNCH	lxxnch	laxxch	MAURCH	maxxch
LOUNGE	lxxnge	loxxge	MOURGE	moxxge
MAIDEN	mxxden	maxxen	NAIFEN	naxxen
NEARBY	nxxrby	nexxby	MEASBY	mexxby
PEANUT	pxxnut	pexxut	REASUT	rexxut
POUNCE	pxxnce	poxxce	SOUSCE	soxxce
READER	rxxder	rexxer	SEAGER	sexxer
SAILOR	sxxlor	saxxor	TAIPOR	taxxor
SAUCER	sxxcer	saxxer	TAUGER	taxxer
TAILOR	txxlor	taxxor	TAMLOY	taxxoy
AFRAID	afrxxd	afxxid	AFSAIL	afxxil
BELIEF	belxxf	bexxef	BEMIEK	bexxek
DETAIL	detxxl	dexxil	DEVAIP	dexxip
DEVOUT	devxxt	dexxut	DEYOUX	dexxux
DOMAIN	domxxn	doxxin	DOPAIR	doxxir
FAMOUS	famxxs	faxxus	FAPOUT	faxxut
JOYOUS	joyxxs	joxxus	JOTOUP	joxxup
OBTAIN	obtxxn	obxxin	OBWAIR	obxxir
ORDEAL	ordxxl	orxxal	ORGEAP	orxxap
RELIEF	relxxf	rexxef	REMIEH	rexxeh
SCREAM	scrxxm	scxxam	SCLEAT	scxxat
SPREAD	sprxxd	spxxad	SPLEAF	spxxaf
STREAM	strxxm	stxxam	STUEAP	stxxap
THREAD	thrxxd	thxxad	THIEAH	thxxah
THROAT	thrxxt	thxxat	THROAD	thxxad

Stimuli in Experiment 2

Words (One Grapheme)			Nonwords (One Grapheme)		
Target	TL Prime	RL Prime	Target	TL Prime	RL Prime
ANTHEM	anhtem	ankfem	ZACKLE	zakcle	zabsle
ASTHMA	ashtma	asblma	VOCKLE	vokcle	vodmle
FARTHER	farhter	farkder	CATHSIC	cahtsic	cafksic
PANTHER	panhter	panlder	UNCHAIC	unhcaic	unfzaic
ORTHODOX	orhtodox	orfkodox	OLCHERD	olhcerd	olknerd
BIRTHDAY	birhtday	birklday	TUNCHAT	tunhcat	tunbvat
DAUGHTER	dauhgter	daubjter	MINCHEON	minhceon	mindreon
PAMPHLET	pamhplet	pamdqlet	ISPHADIC	ishpadic	iskgadic
BIOSPHERE	bioshpere	biostqere	BEOGHTER	beohgter	beokpter

BLASPHEMY	blashpemy	blaslgemy	UNCHATECT	unhcatect	undwatect
PHOSPHATE	phoshpate	phosljate	GRUNCHISE	grunhcise	grunkrise
ANTHOLOGY	anhtology	ankfology	ESPHIBION	eshpibion	esfqibion
ARCHER	arhcer	artner	ONGHEN	onhgen	onkpen
ORCHID	orhcid	orksid	ONCHAD	onhcad	onlmad
ASPHALT	ashpalt	asfqalt	ESPHIN	eshpin	estgin
DOLPHIN	dolhpin	dolkgin	DECKLE	dekcle	detwle
SULPHUR	sulhpur	sultjur	ENPHILT	enhpilt	entgilt
ATHLETE	ahtlete	afblete	RESPHUR	reshpur	resdjur
ALPHABET	alhpabet	alfjabet	INPHABET	inhpabet	indjabet
RHYTHMIC	rhyhtmic	rhydlmic	COMPHURE	comhpure	comljure
CASHMERE	cahsmere	catnmere	OERTHETIC	oerhtetic	oerfletic
MORPHINE	morhpine	morbjine	MOCHNECAL	mohcnecal	molxnecal
TECHNICAL	tehcnical	tebmnical	CLISPHOMY	clishpomy	clisdjomy
FRANCHISE	franhcise	frandxise	CLANCHITIS	clanhcitis	clantwitis
ORPHAN	orhpan	orbgan	URCHIR	urhcir	urlsir
AFGHAN	afhgan	afdjan	ENCHOD	enhcod	entvod
PICKLE	pikcle	pitvle	ITHNETE	ihtnete	ifdnete
TACKLE	takcle	tabwle	GIRTHER	girhter	girbler
ARCHAIC	arhcaic	artsaic	ALPHURYS	alhpurys	altqurys
ARCHING	arhcing	arlning	LISHMIRE	lihsmire	likvmire
SAPPHIRE	saphpire	sapfgire	ENCHIVES	enhcives	entsives
SYMPHONY	symhpony	symkgony	CENPHOSY	cenhposy	cenfgosy
LUNCHEON	lunhceon	lundzeon	ARCHUNTRA	arhcuntra	artmuntra
MERCHANT	merhcant	merfxant	CRISPHITE	crishpite	cristqite
ORCHESTRA	orhcestra	orfwestra	LONTHESYS	lonhtesys	lonfdesys
ARTHRITIS	arhtritis	ardfritis	ESTHILOGY	eshtilogy	esfbilogy
ETHNIC	ehtnic	efdnic	ORCHOVY	orhcovy	orbmovy
ANCHOR	anhcor	anlmor	NURSHAL	nurhsal	nurtcal
TICKLE	tikcle	tidxle	URTHOM	urhtom	urklom
MARSHAL	marhsal	martzal	ERTHME	erhtme	erbfme
ORCHARD	orhcard	orkmard	FISPHIN	fishpin	fiskgin
TRICKLE	trikcle	trihzle	BUSTHER	bushter	buskfer
EMPHASIS	emhpasis	emtgasis	ISTHELOX	ishtelox	iskbelox
ARCHIVES	arhcives	arbsives	GIRPHINE	girhpine	girtqine
SYNTHESIS	synhtesis	synlbesis	CEMPHLIT	cemhplit	cembjlit
ALCHEMIST	alhcemist	altzemist	BRUTHMIC	bruhtmic	bruldmic
ANARCHIST	anarhcist	anarbsist	OSIRCHIST	osirhcist	osirfwist
ARCHITECT	arhcitect	arkvitect	ENTHRITIS	enhtritis	enkbritis

Words (Two Graphemes)			Nonwords (Two Graphemes)		
Target	TL Prime	RL Prime	Target	TL Prime	RL Prime
EMPTY	emtpy	embgy	CONTROG	conrtog	convdog
CORPSE	corspe	cormje	INCLUFE	inlcufe	inhvufe
MARBLE	marlbe	marfke	SPRAKE	srpake	snqake
SPARKLE	sparlke	sparbte	CORCLE	corlce	corfne
INTRUDE	inrtude	incfude	INFLUERCE	inlfuerce	intduerce
CATCHER	cathcer	catlzer	ANARTMENT	anatrment	anafsment
CONFRONT	conrfont	conskont	FANCTION	fantcion	fanksion
SCULPTOR	scultpor	sculkgor	ROMPLETE	romlpete	romdgete
AMPLITUDE	amlpitude	amkgitude	INTRIFSIC	inrtifsic	inskifsic
INFLATION	inlfation	indtation	SANCTUPRY	santcupry	sankvupry
ASTRONOMY	asrtonomy	asmkonomy	CONTRAXICT	conrtaxict	conslaxict
INTRICATE	inrticate	inskicate	CIMPREHEND	cimrpehend	cimvgehend
SAMPLE	samlpe	samtge	HINDLE	hinlde	hinkfe
EMPLOY	emlpoy	emkgoy	SIMPDE	sipmde	sigrde
INFLICT	inlfict	inkdict	STRORPY	stropry	strogmy
DESTROY	desrtoy	desvkoy	NISTRIL	nisrtil	nisvbil
COMPRESS	comrpess	comvjess	TWIFTER	twitfer	twilber
CONCLUDE	conlcude	conhxude	BUFGLAR	buflgar	bufhpar
UMBRELLA	umrbella	umnkella	VORTRAIT	vorrtait	vomsfait
SPECTRUM	specrtum	speclnum	COVTRACT	covrtact	covzdact
SPINSTER	spisnter	spirvter	INSTMUCT	intsmuct	inkrmuct
INTRIGUE	inrtigue	insfigue	RESTRIWT	resrtiwt	resnliwt
ASTROLOGY	asrtology	asvbology	LONCLUSION	lonlcusion	lontzusion
INTRODUCE	inrtoduce	incdoduce	IMPREWSION	imrpewsion	imngewsion
EMBLEM	emlbem	emfdem	AXPLE	axlpe	axkge
EMBRYO	emrbyo	emnhyo	ASGLE	aslge	asbje
RAMBLE	rabmle	rahvle	OLSCURE	olcsure	olnwure
GAMBLE	gamlbe	gamdte	STURGED	stugred	stujced
PILGRIM	pilrgim	pilsqim	WRIZGLE	wrizlge	wriztje
PUMPKIN	pumpkin	pumfgin	COWPRISE	cowrpise	cowngise
MEMBRANE	memrbane	memsfane	ECSTAPIC	ectsapic	ecfxapic
INTREPID	inrtepid	incbepid	EKECTRON	eketcron	ekedmron
CONGRESS	conrgess	conzpess	TRAVSLATE	travlsate	travbcate
ALTRUISM	alrtuism	alcbuism	TRAGSCEND	trasgcend	trazpcend
EXCREMENT	exrcement	exsnement	INFLEGTION	inlfegtion	intkegtion
IMPROVISE	imrpovise	imwqovise	CONCLUWIVE	conlcuwive	condsuwive
HUNGRY	hunrgy	hunspy	HUKDRED	hukrded	hukmfed
JUNGLE	jugnle	juntqe	GAMBWER	gabmwer	gatxwer

ENTROPY	enrtopy	enmdopy	EMBRYCE	emrbyce	emsfyce
OSTRICH	osrtich	osnfich	APSTAIN	aptsain	apkrain
IMPLICIT	imlpicit	imtqicit	CONFLACK	conlfack	conhtack
DOCTRINE	docrtine	doczfine	MONSTANT	montsant	monlrant
COMPLAIN	comlpain	comdjain	JICTION	jitcion	jihvion
RESTRAIN	resrtain	resmdain	SANCTIOK	santciok	sandriok
EXCLUSIVE	exlcusive	exfrusive	ACTRESH	acrtesh	acwlesh
IMPLEMENT	imlpement	imhgement	AMPLISSY	amlpissy	amlqissy
PRESCRIBE	presrcibe	presvnibe	ASTROCOMER	asrtocomer	asmbocomer
CONSTRUCT	consrtuct	conscbuct	ELEMTRONIC	elemrtonic	elemskonic

Stimuli in Experiment 3

CH-Words (One Grapheme)			CH-Nonwords (One Grapheme)		
Target	TL Prime	RL Prime	Target	TL Prime	RL Prime
SALCHICHA	salhcicha	salbnicha	LACHERO	lahcero	latnero
HECHICERO	hehcicero	hedsicero	FACHIZO	fahcizo	fabsizo
PERCHERO	perhcero	perbnero	GOCHERO	gohcero	gobnero
CORCHETES	corhcetes	corbsetes	LOCHINAR	lohcinar	lobsinar
DICHOSO	dihcoso	didsoso	COCHAZAR	cohcazar	codsazar
TECHUMBRE	tehcumbre	tednumbre	FOCHERO	fohcero	fodrero
MECHONES	mehcones	mebnones	SUCHILO	suhcilo	sutsilo
BOCHORNO	bohcorno	bodsorno	PORCHONES	porhcones	potncones
COCHERO	cohcero	codnero	SECHETES	sehcetes	sefsetes
PECHUGA	pehcuga	pebsuga	LOCHINERO	lohcinero	lotninero
HACHAZO	hahcazo	hadsazo	JACHIFRIL	jahcifril	jatsifril
CACHETES	cahcetes	cabnetes	SUCHILA	suhcila	sutrila
MACHACAR	mahcacar	madnacar	JECHADO	jehcado	jefsado
PINCHAZO	pinhcazo	pintsazo	TRENCHADO	trenhcado	trenfnado
PANCHITO	panhcito	panfnito	JOCHARSE	johcarse	jobnarse
FICHAJE	fihcaje	fitsaje	CECHILLER	cehciller	cebsiller
MOCHILA	mohcila	mobsila	SOCHADOR	sohcador	sobnador
FLECHAZO	flehcazo	fletnazo	DECHERO	dehcero	dednero
FACHADA	fahcada	fabsada	SECHAMAR	sehcamar	sedsamar
BICHITO	bihcito	bitnito	POCHORCHO	pohcorcho	podnorcho
RECHAZAR	rehcazar	refnazar	VELCHILLA	velhcilla	veltnilla
FECHADO	fehcado	febsado	POCHARRO	pohcarro	potsarro
LECHUGA	lehcuga	ledsuga	SOCHISTAR	sohcistar	sotvistar
FICHADO	fihcado	fitsado	ROCHISTA	rohcista	rofsista
HECHIZO	hehcizo	hebnizo	RUCHINO	ruhcino	rufnino

RECHONCHO	rehconcho	retnoncho	SOCHACHO	sohcacho	sotracho
CUCHARA	cuhcara	cutsara	PACHERO	pahcero	pabsero
ENCHUFE	enhcufe	enbnufe	CANCHATA	canhcata	canbnata
ARCHIVO	arhcivo	arfsivo	LOCHAZO	lohcazo	lotnazo
BROCHAZO	brohcazo	brotnazo	BERCHILLO	berhcillo	betscillo
RECHINAR	rehcinar	refsinar	SONCHOSO	sonhcoso	sonfsoso
MICHELÍN	mihcelín	mifnelín	VECHETE	vehcete	vetnete
MOCHUELO	mohcuelo	mofnuelo	CRACHAZO	crahcazo	crafnazo
ECHADO	ehcado	ebrado	SUCHONDEO	suhcondeo	subsondeo
DUCHARSE	duhcarse	dubsarse	GACHELÍN	gahcelín	gabselín
PUCHERO	puhcero	pubnero	CECHORNO	cehcorno	cedsorno
MECHERO	mehcero	mebvero	NACHUELO	nahcuelo	nadruelo
MANCHEGO	manhcego	manfnego	JOCHADA	johcada	jodnada
TRINCHERAS	trinhceras	trinfseras	TOCHUGA	tohcuga	tobnuga
MACHETE	mahcete	matnete	BACHUZA	bahcuza	batsuza
OCHENTA	ohcenta	otrenta	LOCHADO	lohcado	lotmado
HORCHATA	horhcata	hortsata	LICHUMBRE	lihcumbre	lifsumbre
TACHADO	tahcado	tafsado	CECHORRO	cehcorro	cefrorro
LUCHADOR	luhcador	lufsador	MONCHERO	monhcero	monfnero
LECHERO	lehcero	lefnero	ASCHUFE	ashcufe	astnufe
FICHERO	fihcero	fibnero	GACHULA	gahcula	gabnula
MUCHACHO	muhcacho	mubsacho	NURCHELES	nurhceles	nurbreles
MANCHADO	manhcado	mandrado	ACHESTA	ahcesta	adresta
TRINCHERA	trinhcera	trindnera	DACHILLO	dahcillo	dadnillo
CACHARRO	cahcarro	cadsarro	GUCHORÍA	guhcoría	gudsoría
LECHUZA	lehcuza	letsuza	CECHARA	cehcara	cedsara
CUCHITRIL	cuhcitril	cutnitril	LENCHADO	lenhcado	lentsado
COCHINO	cohcino	cofrino	PRECHAZO	prehcazo	prefrazo
RECHISTAR	rehcistar	refsistar	OCHABO	ohcabo	obnabo
FECHORÍA	fehcoría	fefnoría	FORCHADO	forhcado	fortnado
CACHONDEO	cahcondeo	cadnondeo	GOCHOSO	gohcoso	gobnoso
GANCHILLO	ganhcillo	gandsillo	LARCHERA	larhcera	larbsera
MARCHOSO	marhcoso	mardsoso	NOCHADO	nohcado	nobrado
CUCHILLO	cuhcillo	cudmillo	PISCHEGO	pishcego	pisdnego
PLANCHADO	planhcado	planbsado	SIRCHAZO	sirhcazo	sirdnazo
MACHETES	mahcetes	mabsetes	JENCHERAS	jenhceras	jendreras
COLCHONES	colhcones	colbnones	ISCHIVO	ishcivo	istrivo
BACHILLER	bahciller	batmiller	LACHAJE	lahcaje	ladvaje
MACHISTA	mahcista	marnista	SUCHONES	suhcones	sudmones

Non-CH-Words (Two Graphemes)			Non-CH-Nonwords (Two Graphemes)		
Target	TL Prime	RL Prime	Target	TL Prime	RL Prime
SECRETARIA	sercetaria	senvetaria	REBRADA	rerbada	rendada
TÉTRICO	tértico	tésfico	LEBLETA	lelbeta	letdeta
INSCRIBIR	insrcibir	insnsibir	ISBROLLO	isrbollo	issdollo
LACRADO	larcado	lamrado	SUCRETO	surceto	sunveto
SUBLEVAR	sulbevar	suftevar	URFLADO	urlfado	urtdado
RECLUTAR	relcutar	refnutar	LUFLETES	lulfetes	ludbetes
MEMBRANA	memrbana	memndana	PEBLAJE	pelbaje	petfaje
ESTRIBO	esrtibo	essfibo	PEBLERO	pelbero	pefdero
MALTRATO	malrtato	malnfato	TOCLISMO	tolcismo	tofsismo
BÍBLICO	bílbico	bífdico	CUNTRITO	cunrtito	cunsfito
ESCLAVO	eslcavo	esfnavo	SORTRADO	sorrtado	sornlado
MICROBIO	mircobio	minsobio	RUSCRIDIR	rusrcidir	russnidir
SECRETO	serceto	senseto	MUCRETO	murceto	munseto
DECRETO	derceto	denveto	LUNCRITO	lunrcito	lunvsito
REFRESCAR	rerfescar	remtescar	IRCLAMAR	irlcamar	irtnamar
LETRERO	lertero	lenfero	JECRADO	jercado	jesvado
ATRASO	artaso	anfaso	ECRÓDATA	ercódata	ensódata
RECLUSO	relcuso	retsuso	REBLAZO	relbazo	retfazo
MEZCLADO	mezlcado	meztsado	TOCLUTAR	tolcutar	tofnutar
ENCLAVE	enlcave	enfmave	LEBLILLA	lelbilla	letdilla
REFRANES	rerfanes	remlanes	REMFLETO	remlfeto	remtbeto
INFLADO	inlfado	intdado	UBRAZO	urbazo	undazo
ACRÓBATA	arcóbata	ansóbata	ERCREPAR	errcepar	ersmepar
TABLILLA	talbilla	tafdilla	CICRODIO	circodio	cimsodio
TABLONES	talbones	tadtones	TOBLEVAR	tolbevar	tofdevar
DOBLAJE	dolbaje	doftaje	TOBLADO	tolbado	totdado
ECLIPSE	elcipse	etnipse	GÓBLICO	gólbico	góftico
TABLETA	talbeta	tafdeta	SACLUSO	salcuso	satnuso
RECLAMAR	relcamar	retsamar	PERTROJOS	perrtojos	perslojos
DISFRACES	disrfaces	disstaces	GATRICO	gartico	gasfico
CICLISMO	cilcismo	citnismo	PROFLADO	prolfado	protdado
PANFLETO	panlfeto	pantbeto	SURBLORES	surlbores	surdtores
CHIFLADO	chilfado	chitdado	CABRINO	carbino	candino
ENCLENQUE	enlcenque	enbsenque	SUBRONES	surbones	sustones
CICLONES	cilcones	citsones	ETRANO	ertano	enlano
ABRAZO	arbazo	antazo	TACLIVE	talcive	tafsive
NUTRIENTE	nurtiente	nunliente	CECROARDAS	cercoardas	cenvoardas
DISTRITO	disrtito	dissfito	ROSTRADO	rosrtado	rosmlado

FILTRADO	filrtado	filslado	URCLENQUE	urlcenque	urtsenque
SACRISTÁN	sarcistán	sansistán	TONFRACES	tonrfaces	tonnlaces
RASTROJOS	rasrtojos	rasnlojos	LORTRATO	lorrtato	lorslato
DESCRITO	desrcito	desnsito	PANCLADO	panlcado	pantsado
DECLIVE	delcive	defsive	ANTRIBO	anrtibo	annfibo
DECRECER	dercecer	densecer	SUTRINA	surtina	sumlina
PROCREAR	prorcear	pronsear	PECRISTÁN	percistán	pesnistán
CABRONES	carbones	camtones	DOCLABO	dolcabo	dotsabo
EXCLAMAR	exlcamar	extsamar	TUCLAMAR	tulcamar	tufnamar
MOFLETES	molfetes	motfetes	CUBLADOR	culbador	cutfador
TECLADO	telcado	tetsado	ORCLADO	orlcado	orfsado
NUBLADO	nulbado	nufdado	VICREMARIA	vircemaria	vinsemaria
HABLADOR	halbador	hatfador	DACRENER	darcener	davnener
EMBROLLO	emrbollo	emndollo	INCLAVO	inlcavo	intsavo
ANCLADO	anlcado	antnado	LEBLORES	lelbores	letdores
TABLERO	talbero	tafdero	CLUCREAR	clurcear	clusnear
TEMBLORES	temlbores	temtdores	COTRERO	cortero	conlero
INCLINAR	inlcinar	intminar	SECLONES	selcones	setsones
VITRINA	virtina	vislina	OCLIGSE	olcigse	otnigse
SOBRINO	sorbino	sondino	ORCLINAR	orlcinar	orfminar
CENTRADO	cenrtado	censlado	MOBRETO	morbeto	mondeto
DISCRETO	disrceto	disnveto	OSCLAVE	oslcave	ostsave
SABLAZO	salbazo	satdazo	CUSBRANA	cusrbana	cusmdana
INCREPAR	inrcepar	insnepar	PERCRETO	perrceto	pernseto
POBLADO	polbado	potdado	LEBLADO	lelbado	letdado
MICROONDAS	mircoondas	minsoondas	LIFRANES	lirfanes	lintanes

Stimuli in Experiment 4 TL and RL primes

CH-Words (One Grapheme)			CH-Nonwords (One Grapheme)		
Target	TL Prime	RL Prime	Target	TL Prime	RL Prime
SALCHICHA	salcihcha	salvibcha	LACHERO	lacehro	lasedro
HECHICERO	hecihcero	heritcero	FACHIZO	facihzo	fasitzo
PERCHERO	percehro	pernedro	GOCHERO	gocehro	govedro
CORCHETES	corcehtes	cormebtes	LOCHINAR	locihnar	lonilnar
DICHOSO	dicohso	disobso	COCHAZAR	cocahzar	cosabzar
TECHUMBRE	tecuhmbre	terudmbre	FOCHERO	focehro	fovelro
MECHONES	mecohnes	menobnes	SUCHILO	sucihlo	suniblo
BOCHORNO	bocohrno	bovolrno	PORCHONES	porcohnes	porsobnes
COCHERO	cocehro	conedro	SECHETES	secehtes	sereltes

PECHUGA	pecuhga	perutga	LOCHINERO	locihnero	lositnero
HACHAZO	hacahzo	haradzo	JACHIFRIL	jacihfril	jasilfril
CACHETES	cacehtes	cavebtes	SUCHILA	sucihla	suvitla
MACHACAR	macahcar	masabcar	JECHADO	jecahdo	jesatdo
PINCHAZO	pincahzo	pinradzo	TRENCHADO	trancahdo	tranratdo
PANCHITO	pancihto	panmidto	JOCHARSE	jocahrse	josatrse
FICHAJE	ficahje	fisadje	CECHILLER	cecihller	cenitller
MOCHILA	mocihla	movidla	SOCHADOR	socahdor	sovaldor
FLECHAZO	flecahzo	flesatzo	DECHERO	decehro	deretro
FACHADA	facahda	fanatda	SECHAMAR	secahmar	sevalmar
BICHITO	bicihto	birikto	POCHORCHO	pocohrcho	povodrcho
RECHAZAR	recahzar	resadzar	VELCHILLA	velcihlla	velsiblla
FECHADO	fecahdo	fevatdo	POCHARRO	pocahrro	poradrro
LECHUGA	lecuhga	lenutga	SOCHISTAR	socihstar	sonilstar
FICHADO	ficahdo	finatdo	ROCHISTA	rocihsta	rovitsta
HECHIZO	hecihzo	henitzo	RUCHINO	rucihno	rubitno
RECHONCHO	recohncho	resotncho	SOCHACHO	socahcho	sovalcho
CUCHARA	cucahra	cuvalra	PACHERO	pacehro	pasebro
ENCHUFE	encuhfe	enrutfe	CANCHATA	carcahta	carsalta
ARCHIVO	arcihvo	arsidvo	LOCHAZO	locahzo	lorabzo
BROCHAZO	brocahzo	brosabzo	BERCHILLO	bencihllo	bennidllo
RECHINAR	recihnar	remidnar	SONCHOSO	soncohso	sonsolso
MICHELÍN	micehlín	mineblín	VECHETE	vecehte	vevelte
MOCHUELO	mocuhelo	morubelo	CRACHAZO	cracahzo	crasabzo
ECHADO	ecahdo	evakdo	SUCHONDEO	sucohndeo	surotndeo
DUCHARSE	ducahrse	dusalrse	GACHELÍN	gacehlín	garetlín
PUCHERO	pucehro	pusedro	CECHORNO	cecohrno	cesotrno
MECHERO	mecehro	menedro	NACHUELO	nacuhelo	nasulelo
MANCHEGO	mancehgo	manretgo	JOCHADA	jocahda	josatda
TRINCHERAS	trincehras	trinvelras	TOCHUGA	tocuhga	tonulga
MACHETE	macehte	mavedte	BACHUZA	bacuhza	bavudza
OCHENTA	ocehnta	omednta	LOCHADO	locahdo	losafdo
HORCHATA	horcahta	hornabta	LICHUMBRE	licuhmbre	lisubmbre
TACHADO	tacahdo	tanabdo	CECHORRO	cecohrro	cesolrro
LUCHADOR	lucahdor	lusabdor	MONCHERO	moncehro	monrebro
LECHERO	lecehro	lesetro	ASCHUFE	ascuhfe	asnudfe
FICHERO	ficehro	fivedro	GACHULA	gacuhla	gasubla
MUCHACHO	mucahcho	munatcho	NURCHELES	nurcehles	nurmetles
MANCHADO	mancahdo	manratdo	ACHESTA	acehsta	anetsta
TRINCHERA	trincehra	trinsebra	DACHILLO	dacihllo	dasibllo

CACHARRO	cacahrro	canabrro	GUCHORÍA	gucohría	gurotría
LECHUZA	lecuhza	levulza	CECHARA	cecahra	cenabra
CUCHITRIL	cucihtril	cusidtril	LENCHADO	lencahdo	lenraldo
COCHINO	cocihno	covitno	PRECHAZO	precahzo	presalzo
RECHISTAR	recihstar	rerilstar	OCHABO	ocahbo	ovalbo
FECHORÍA	fecohría	femobría	FORCHADO	forcahdo	fornatdo
CACHONDEO	cacohndeo	cavolndeo	GOCHOSO	gocohso	gonotso
GANCHILLO	gancihllo	ganridllo	LARCHERA	larcehra	larnetra
MARCHOSO	marcohso	marnolso	NOCHADO	nocahdo	noraldo
CUCHILLO	cucihllo	cunidllo	PISCHEGO	piscehgo	pisnelgo
PLANCHADO	plancahdo	planmabdo	SIRCHAZO	sircahzo	sirsatzo
MACHETES	macehtes	mavedtes	JENCHERAS	jencehras	jensebras
COLCHONES	colcohnes	colrotnes	ISCHIVO	iscihvo	isbilvo
BACHILLER	bacihller	basidller	LACHAJE	lacahje	lasadje
MACHISTA	macihsta	masibsta	SUCHONES	sucohnes	surotnes
SALCHICHA	salcihcha	salvibcha	LACHERO	lacehro	lasedro
HECHICERO	hecihcero	heritcero	FACHIZO	facihzo	fasitzo
PERCHERO	percehro	pernedro	GOCHERO	gocehro	govedro
CORCHETES	corcehtes	cormebtes	LOCHINAR	locihnar	lonilnar
DICHOSO	dicohso	disobso	COCHAZAR	cocahzar	cosabzar
TECHUMBRE	tecuhmbre	terudmbre	FOCHERO	focehro	fovelro
MECHONES	mecohnes	menobnes	SUCHILO	sucihlo	suniblo
BOCHORNO	bocohrno	bovolrno	PORCHONES	porcohnes	porsobnes
COCHERO	cocehro	conedro	SECHETES	secehtes	sereltes
PECHUGA	pecuhga	perutga	LOCHINERO	locihnero	lositnero
HACHAZO	hacahzo	haradzo	JACHIFRIL	jacihfril	jasilfril
CACHETES	cacehtes	cavebtes	SUCHILA	sucihla	suvitla
MACHACAR	macahcar	masabcar	JECHADO	jecahdo	jesatdo
PINCHAZO	pincahzo	pinradzo	TRENCHADO	trancahdo	tranratdo
PANCHITO	pancihto	panmidto	JOCHARSE	jocahrse	josatrse
FICHAJE	ficahje	fisadje	CECHILLER	cecihller	cenitller
MOCHILA	mocihla	movidla	SOCHADOR	socahdor	sovaldor
FLECHAZO	flecahzo	flesatzo	DECHERO	decehro	deretro
FACHADA	facahda	fanatda	SECHAMAR	secahmar	sevalmar
BICHITO	bicihto	birikto	POCHORCHO	pocohrcho	povodrcho
RECHAZAR	recahzar	resadzar	VELCHILLA	velcihlla	velsiblla
FECHADO	fecahdo	fevatdo	POCHARRO	pocahrro	poradrro
LECHUGA	lecuhga	lenutga	SOCHISTAR	socihstar	sonilstar
FICHADO	ficahdo	finatdo	ROCHISTA	rocihsta	rovitsta
HECHIZO	hecihzo	henitzo	RUCHINO	rucihno	rubitno

RECHONCHO	recohncho	resotncho	SOCHACHO	socahcho	sovalcho
CUCHARA	cucahra	cuvalra	PACHERO	pacehro	pasebro
ENCHUFE	encuhfe	enrutfe	CANCHATA	carcahta	carsalta
ARCHIVO	arcihvo	arsidvo	LOCHAZO	locahzo	lorabzo
BROCHAZO	brocahzo	brosabzo	BERCHILLO	bencihllo	bennidllo
RECHINAR	recihnar	remidnar	SONCHOSO	soncohso	sonsolso
MICHELÍN	micehlín	mineblín	VECHETE	vecehte	vevelte
MOCHUELO	mocuhelo	morubelo	CRACHAZO	cracahzo	crasabzo
ECHADO	ecahdo	evakdo	SUCHONDEO	sucohndeo	surotndeo
DUCHARSE	ducahrse	dusalrse	GACHELÍN	gacehlín	garetlín
PUCHERO	pucehro	pusedro	CECHORNO	cecohrno	cesotrno
MECHERO	mecehro	menedro	NACHUELO	nacuhelo	nasulelo
MANCHEGO	mancehgo	manretgo	JOCHADA	jocahda	josatda
TRINCHERAS	trincehras	trinvelras	TOCHUGA	tocuhga	tonulga
MACHETE	macehte	mavedte	BACHUZA	bacuhza	bavudza
OCHENTA	ocehnta	omednta	LOCHADO	locahdo	losafdo
HORCHATA	horcahta	hornabta	LICHUMBRE	licuhmbre	lisubmbre
TACHADO	tacahdo	tanabdo	CECHORRO	cecohrro	cesolrro
LUCHADOR	lucahdor	lusabdor	MONCHERO	moncehro	monrebro
LECHERO	lecehro	lesetro	ASCHUFE	ascuhfe	asnudfe
FICHERO	ficehro	fivedro	GACHULA	gacuhla	gasubla
MUCHACHO	mucahcho	munatcho	NURCHELES	nurcehles	nurmetles
MANCHADO	mancahdo	manratdo	ACHESTA	acehsta	anetsta
TRINCHERA	trincehra	trinsebra	DACHILLO	dacihllo	dasibllo
CACHARRO	cacahrro	canabrro	GUCHORÍA	gucohría	gurotría
LECHUZA	lecuhza	levulza	CECHARA	cecahra	cenabra
CUCHITRIL	cucihtril	cusidtril	LENCHADO	lencahdo	lenraldo
COCHINO	cocihno	covitno	PRECHAZO	precahzo	presalzo
RECHISTAR	recihstar	rerilstar	OCHABO	ocahbo	ovalbo
FECHORÍA	fecohría	femobría	FORCHADO	forcahdo	fornatdo
CACHONDEO	cacohndeo	cavolndeo	GOCHOSO	gocohso	gonotso
GANCHILLO	gancihllo	ganridllo	LARCHERA	larcehra	larnetra
MARCHOSO	marcohso	marnolso	NOCHADO	nocahdo	noraldo
CUCHILLO	cucihllo	cunidllo	PISCHEGO	piscehgo	pisnelgo
PLANCHADO	plancahdo	planmabdo	SIRCHAZO	sircahzo	sirsatzo
MACHETES	macehtes	mavedtes	JENCHERAS	jencehras	jensebras
COLCHONES	colcohnes	colrotnes	ISCHIVO	iscihvo	isbilvo
BACHILLER	bacihller	basidller	LACHAJE	lacahje	lasadje
MACHISTA	macihsta	masibsta	SUCHONES	sucohnes	surotnes

Non-CH-Words (Two Graphemes)		
Target	TL Prime	RL Prime
SECRETARIA	secertaria	senestaria
TÉTRICO	tétirco	tébinco
INSCRIBIR	inscirbir	insnimbir
LACRADO	lacardo	lasamdo
SUBLEVAR	subelvar	sudetvar
RECLUTAR	recultar	rerudtar
MEMBRANA	membarna	memdasna
ESTRIBO	estirbo	eslinbo
MALTRATO	maltarto	mallasto
BÍBLICO	bíbilco	bíditco
ESCLAVO	escalvo	esnatvo
MICROBIO	micorbio	misonbio
SECRETO	secerto	senesto
DECRETO	decerto	desento
REFRESCAR	referscar	retevscar
LETRERO	leterro	lelesro
ATRASO	atarso	alavso
RECLUSO	reculso	remudso
MEZCLADO	mezcaldo	meznatdo
ENCLAVE	encalve	ensadve
REFRANES	refarnes	refasnes
INFLADO	infaldo	intabdo
ACRÓBATA	acórbata	anósbata
TABLILLA	tabillla	taditlla
TABLONES	tabolnes	tadotnes
DOBLAJE	dobalje	dodatje
ECLIPSE	ecilpse	esitpse
TABLETA	tabelta	tadehta
RECLAMAR	recalmar	resatmar
DISFRACES	disfarces	disbances
CICLISMO	cicilsmo	cisitsmo
PANFLETO	panfelto	pantedto
CHIFLADO	chifaldo	chibatdo
ENCLENQUE	encelnque	ensetnque
CICLONES	cicolnes	cisotnes
ABRAZO	abarzo	adanzo
NUTRIENTE	nutirente	nulivente
DISTRITO	distirto	dislimto

Non-CH-Nonwords (Two Graphemes)		
Target	TL Prime	RL Prime
REBRADA	rebarda	retanda
LEBLETA	lebelta	letedta
ISBROLLO	isborllo	isdonllo
SUCRETO	sucerto	susento
URFLADO	urfaldo	urtabdo
LUFLETES	lufeltes	lutedtes
PEBLAJE	pebalje	pedalje
PEBLERO	pebelro	pedetro
TOCLISMO	tocilsmo	tosifsmo
CUNTRITO	cuntirto	cunfinto
SORTRADO	sortardo	sorfando
RUSCRIDIR	ruscirdir	rusnivdir
MUCRETO	mucerto	musento
LUNCRITO	luncirto	lunsinto
IRCLAMAR	ircalmar	irsatmar
JECRADO	jecardo	jesando
ECRÓDATA	ecórdata	enósdata
REBLAZO	rebalzo	refatzo
TOCLUTAR	tocultar	tonudtar
LEBLILLA	lebillla	leditlla
REMFLETO	renfelto	rentedto
UBRAZO	ubarzo	udanzo
ERCREPAR	ercerpar	ersenpar
CICRODIO	cicordio	cisonvio
TOBLEVAR	tobelvar	todetvar
TOBLADO	tobaldo	todafdo
GÓBLICO	góbilco	góditco
SACLUSO	saculso	sanutso
PERTROJOS	pertorjos	perlonjos
GATRICO	gatirco	galinco
PROFLADO	profaldo	protabdo
SURBLORES	surbolres	surdotres
CABRINO	cabirno	cadisno
SUBRONES	subornes	sudosnes
ETRANO	etarno	elasno
TACLIVE	tacilve	tanitve
CECROARDAS	cecorardas	cesonardas
ROSTRADO	rostardo	roslacdo

FILTRADO	filtardo	fillando	URCLENQUE	urcelnque	urnetnque
SACRISTÁN	sacirstán	savinstán	TONFRACES	tonfarces	tontances
RASTROJOS	rastorjos	rasbonjos	LORTRATO	lortarto	lorbanto
DESCRITO	descirto	desnisto	PANCLADO	pancaldo	pansatdo
DECLIVE	decilve	desitve	ANTRIBO	antirbo	anlinbo
DECRECER	decercer	desencer	SUTRINA	sutirna	sulisna
PROCREAR	procerar	prosenar	PECRISTÁN	pecirstán	pevinstán
CABRONES	cabornes	cadosnes	DOCLABO	docalbo	donatbo
EXCLAMAR	excalmar	exnatmar	TUCLAMAR	tucalmar	tusatmar
MOFLETES	mofeltes	motedtes	CUBLADOR	cubaldor	cudafdor
TECLADO	tecaldo	tezatdo	ORCLADO	orcaldo	ornafdo
NUBLADO	nubaldo	nudatdo	VICREMARIA	vicermaria	vinesmaria
HABLADOR	habaldor	hadatdor	DACRENER	dacerner	davesner
EMBROLLO	emborllo	emdonllo	INCLAVO	incalvo	innatvo
ANCLADO	ancaldo	ansatdo	LEBLORES	lebolres	ledotres
TABLERO	tabelro	tadetro	CLUCREAR	clucerar	cluvenar
TEMBLORES	tembolres	temdotres	COTRERO	coterro	cobenro
INCLINAR	incilnar	insitnar	SECLONES	secolnes	senotnes
VITRINA	vitirna	vilimna	OCLIGSE	ocilgse	ositgse
SOBRINO	sobirno	sodimno	ORCLINAR	orcilnar	ornifnar
CENTRADO	centardo	cenbando	MOBRETO	moberto	modento
DISCRETO	discerto	disnesto	OSCLAVE	oscalve	ossatve
SABLAZO	sabalzo	sadatzo	CUSBRANA	cusbarna	cusdasna
INCREPAR	incerpar	insenpar	PERCRETO	percerto	pernemto
POBLADO	pobaldo	podatdo	LEBLADO	lebaldo	ledafdo
MICROONDAS	micorondas	minovondas	LIFRANES	lifarnes	litasnes

Stimuli in Experiment 4 DL and SL primes

CH-Words (One Grapheme)			CH-Nonwords (One Grapheme)		
Target	DL Prime	SL Prime	Target	DL Prime	SL Prime
SALCHICHA	salcicha	salvicha	LACHERO	lacero	lasero
HECHICERO	hecicero	henicero	FACHIZO	facizo	fanizo
PERCHERO	percero	persero	GOCHERO	gocero	gosero
CORCHETES	corcetes	cormetes	LOCHINAR	locinar	losinar
DICHOSO	dicoso	divoso	COCHAZAR	cocazar	conazar
TECHUMBRE	tecumbre	tenumbre	FOCHERO	focero	forero
MECHONES	mecones	merones	SUCHILO	sucilo	suniro
BOCHORNO	bocorno	bosorno	PORCHONES	porcones	porsones
COCHERO	cocero	comero	SECHETES	secetes	sesetes

PECHUGA	pecuga	pesuga	LOCHINERO	locicero	losicero
HACHAZO	hacazo	hasazo	JACHIFRIL	jacifril	jasifril
CACHETES	cacetes	canetes	SUCHILA	sucila	sumila
MACHACAR	macacar	masacar	JECHADO	jecado	jemado
PINCHAZO	pincazo	pinsazo	TRENCHADO	trencado	trescado
PANCHITO	pancito	pansito	JOCHARSE	jocarse	josarse
FICHAJE	ficaje	fisaje	CECHILLER	ceciller	ceriller
MOCHILA	mocila	monila	SOCHADOR	socador	sorador
FLECHAZO	flecazo	flenazo	DECHERO	decero	derero
FACHADA	facada	farada	SECHAMAR	secamar	seramar
BICHITO	bicito	birito	POCHORCHO	pocorcho	posorcho
RECHAZAR	recazar	resazar	VELCHILLA	velcilla	velrilla
FECHADO	fecado	fesado	POCHARRO	pocarro	ponarro
LECHUGA	lecuga	leruga	SOCHISTAR	socistar	soristar
FICHADO	ficado	fimado	ROCHISTA	rocista	ronista
HECHIZO	hecizo	henizo	RUCHINO	rucino	rusino
RECHONCHO	reconcho	resoncho	SOCHACHO	socacho	somacho
CUCHARA	cucara	cunara	PACHERO	pacero	pasero
ENCHUFE	encufe	enmufe	CANCHATA	cancata	cansata
ARCHIVO	arcivo	arnivo	LOCHAZO	locazo	losazo
BROCHAZO	brocazo	brorazo	BERCHILLO	bercillo	bernillo
RECHINAR	recinar	reminar	SONCHOSO	soncoso	sorcoso
MICHELÍN	micelín	minelín	VECHETE	vecete	vesete
MOCHUELO	mocuelo	moruelo	CRACHAZO	cracazo	crasazo
ECHADO	ecado	enado	SUCHONDEO	sucondeo	surondeo
DUCHARSE	ducarse	dunarse	GACHELÍN	gacelín	garelín
PUCHERO	pucero	puvero	CECHORNO	cecorno	cesorno
MECHERO	mecero	menero	NACHUELO	nacuelo	nanuelo
MANCHEGO	mancego	mansego	JOCHADA	jocada	josada
TRINCHERAS	trinceras	trinseras	TOCHUGA	tocuga	tonuga
MACHETE	macete	masete	BACHUZA	bacuza	baruza
OCHENTA	ocenta	osenta	LOCHADO	locado	lorado
HORCHATA	horcata	hornata	LICHUMBRE	licumbre	linumbre
TACHADO	tacado	tanado	CECHORRO	cecorro	cerorro
LUCHADOR	lucador	lunador	MONCHERO	moncero	monsero
LECHERO	lecero	lerero	ASCHUFE	ascufe	asnufe
FICHERO	ficero	fimero	GACHULA	gacula	garula
MUCHACHO	mucacho	munacho	NURCHELES	nurcetes	nurnetes
MANCHADO	mancado	manrado	ACHESTA	acesta	anesta
TRINCHERA	trincera	trinrera	DACHILLO	dacillo	darillo

CACHARRO	cacarro	casarro	GUCHORÍA	gucoría	gusoría
LECHUZA	lecuza	leruza	CECHARA	cecara	cemara
CUCHITRIL	cucitril	cusitril	LENCHADO	lencado	lenrado
COCHINO	cocino	corino	PRECHAZO	precazo	prenazo
RECHISTAR	recistar	renistar	OCHABO	ocabo	omabo
FECHORÍA	fecoría	fevoría	FORCHADO	forcado	fornado
CACHONDEO	cacondeo	casondeo	GOCHOSO	gocoso	goroso
GANCHILLO	gancillo	ganrillo	LARCHERA	larcera	larmera
MARCHOSO	marcoso	marsoso	NOCHADO	nocado	norado
CUCHILLO	cucillo	cumillo	PISCHEGO	piscego	pisnego
PLANCHADO	plancado	planmado	SIRCHAZO	sircazo	sirnazo
MACHETES	macetes	mavetes	JENCHERAS	jenceras	jenseras
COLCHONES	colcones	colmones	ISCHIVO	iscivo	isrivo
BACHILLER	baciller	bamiller	LACHAJE	lacaje	lasaje
MACHISTA	macista	manista	SUCHONES	sucones	sumones

Non-CH-Words (Two Graphemes)			Non-CH-Nonwords (Two Graphemes)		
Target	DL Prime	SL Prime	Target	DL Prime	SL Prime
SECRETARIA	secetaria	senetaria	REBRADA	rebada	relada
TÉTRICO	tético	télico	LEBLETA	lebeta	ledeta
INSCRIBIR	inscibir	insnibir	ISBROLLO	isbollo	isdollo
LACRADO	lacado	lamado	SUCRETO	suceto	suseto
SUBLEVAR	subevar	sudevar	URFLADO	urfado	urbado
RECLUTAR	recutar	resutar	LUFLETES	lufetes	ludetes
MEMBRANA	membana	memtana	PEBLAJE	pebaje	pedaje
ESTRIBO	estibo	eslibo	PEBLERO	pebero	petero
MALTRATO	maltato	malbato	TOCLISMO	tocismo	tonismo
BÍBLICO	bíbico	bítico	CUNTRITO	cuntito	cunbito
ESCLAVO	escavo	esravo	SORTRADO	sortado	sorfado
MICROBIO	micobio	misobio	RUSCRIDIR	ruscidir	rusnidir
SECRETO	seceto	seneto	MUCRETO	muceto	museto
DECRETO	deceto	deseto	LUNCRITO	luncito	lunmito
REFRESCAR	refescar	retescar	IRCLAMAR	ircamar	irsamar
LETRERO	letero	lebero	JECRADO	jecado	jesado
ATRASO	ataso	alaso	ECRÓDATA	ecódata	esódata
RECLUSO	recuso	reruso	REBLAZO	rebazo	redazo
MEZCLADO	mezcado	meznado	TOCLUTAR	tocutar	tonutar
ENCLAVE	encave	ensave	LEBLILLA	lebilla	ledilla
REFRANES	refanes	relanes	REMFLETO	remfeto	remteto
INFLADO	infado	intado	UBRAZO	ubazo	udazo

ACRÓBATA	acóbata	amóbata	ERCREPAR	ercepar	ernepar
TABLILLA	tabilla	tadilla	CICRODIO	cicodio	cimodio
TABLONES	tabones	tadones	TOBLEVAR	tobevar	totevar
DOBLAJE	dobaje	dodaje	TOBLADO	tobado	totado
ECLIPSE	ecipse	eripse	GÓBLICO	góbico	gódico
TABLETA	tabeta	tadeta	SACLUSO	sacuso	sanuso
RECLAMAR	recamar	resamar	PERTROJOS	pertojos	perlojos
DISFRACES	disfaces	distaces	GATRICO	gatico	gadico
CICLISMO	cicismo	cisismo	PROFLADO	prifado	pritado
PANFLETO	panfeto	panbeto	SURBLORES	surbores	surtores
CHIFLADO	chifado	chitado	CABRINO	cabino	catino
ENCLENQUE	encenque	ensenque	SUBRONES	subones	sudones
CICLONES	cicones	cinones	ETRANO	etano	elano
ABRAZO	abazo	atazo	TACLIVE	tacive	tanive
NUTRIENTE	nutiente	nuliente	CECROARDAS	cecoardas	cenoardas
DISTRITO	distito	dislito	ROSTRADO	rostado	roslado
FILTRADO	filtado	filbado	URCLENQUE	urcenque	urnenque
SACRISTÁN	sacistán	savistán	TONFRACES	tonfaces	tonlaces
RASTROJOS	rastojos	raslojos	LORTRATO	lortato	lorlato
DESCRITO	descito	desnito	PANCLADO	pancado	panrado
DECLIVE	decive	desive	ANTRIBO	antibo	anlibo
DECRECER	dececer	desecer	SUTRINA	sutina	sulina
PROCREAR	procear	pronear	PECRISTÁN	pecistán	penistán
CABRONES	cabones	cadones	DOCLABO	docado	dosado
EXCLAMAR	excamar	exramar	TUCLAMAR	tucamar	tunamar
MOFLETES	mofetes	mobetes	CUBLADOR	cubador	cutador
TECLADO	tecado	tesado	ORCLADO	orcado	orsado
NUBLADO	nubado	nutado	VICREMARIA	vicemaria	visemaria
HABLADOR	habador	hadador	DACRENER	dacener	damener
EMBROLLO	embollo	emdollo	INCLAVO	incavo	inravo
ANCLADO	ancado	ansado	LEBLORES	lebores	ledores
TABLERO	tabero	tadero	CLUCREAR	clocear	closear
TEMBLORES	tembores	temtores	COTRERO	cotero	cobero
INCLINAR	incinar	insinar	SECLONES	secones	senones
VITRINA	vitina	vilina	OCLIGSE	ocigse	onigse
SOBRINO	sobino	sodino	ORCLINAR	orcinar	orsinar
CENTRADO	centado	cendado	MOBRETO	mobeto	moleto
DISCRETO	disceto	disneto	OSCLAVE	oscave	osmave
SABLAZO	sabazo	sadazo	CUSBRANA	cusbana	custana
INCREPAR	incepar	insepar	PERCRETO	perceto	permeto

POBLADO	pobado	pohado	LEBLADO	lebado	ledado
MICROONDAS	micoondas	misoondas	LIFRANES	lifanes	litanes