Journal of Experimental Psychology: Human Perception and Performance, in press

# An Investigation of the Role of Grapheme Units in Word Recognition

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## 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.

Results

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 $F$s < 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 *p*s > .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 *p*s>.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 *p*s>.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.

Method

*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

This research was partially supported by ESRC grant RES-000-22-3354 to Colin J. Davis and Stephen J. Lupker, Grant PSI2008-04069/PSIC from the Spanish Ministry of Science and Innovation to Manuel Perea and Natural Sciences and Engineering Research Council of Canada Grant A6333 to Stephen J. Lupker. The authors would like to thank Kieren Eyles, Lindsay Chan and Jason Perry for their assistance in testing participants and analyzing data as well as Max Coltheart, Sachiko Kinoshita, Arnaud Rey, Jennifer Stolz and Carol Whitney for their comments on earlier versions of the manuscript. Portions of this paper were reported at the 17th meeting of the European Society for Cognitive Psychology and the 52nd annual meeting of the Psychonomic Society.

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## 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) |

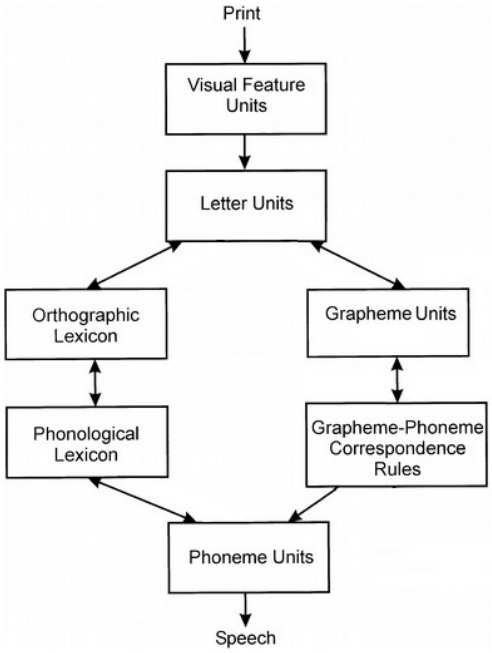
CH=target containing a CH grapheme, TL=transposed-letter condition, RL=replacement-letter condition, TL effect= difference between RL and TL conditions, DL=deleted-letter condition, SL=substituted-letter condition, DL effect=difference between DL and SL conditions.

*Figure Captions*

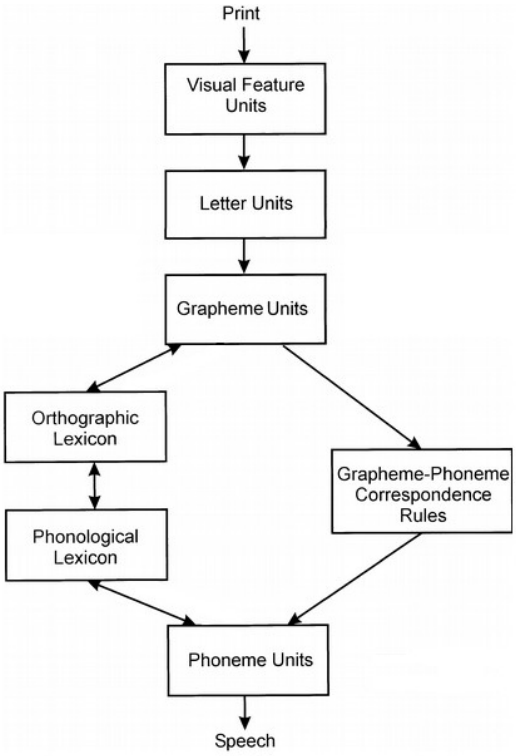
Figure 1: Two possible versions of a dual-route model of visual word recognition. (a) a letter-input model, in which the common input to both routes comes from a level of (abstract) letter units, and (b) a grapheme-input model, in which the common input to both routes comes from a level of grapheme units. 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.

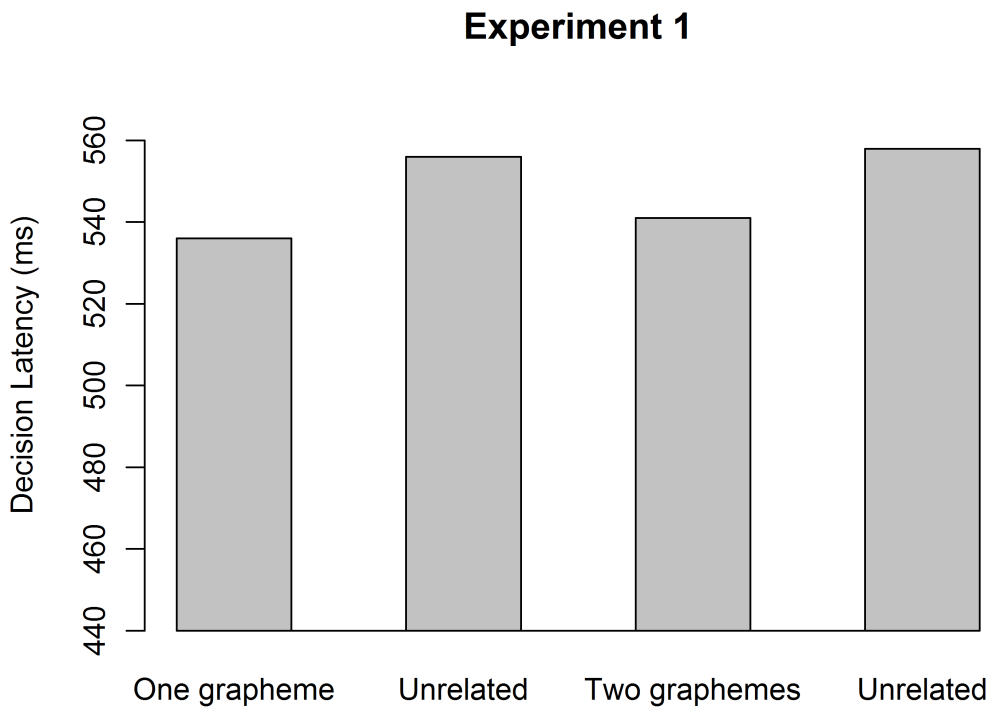
Figure 3: Observed priming effects for the prime conditions in Experiment 2 and corresponding predicted priming effects in Simulation 2.

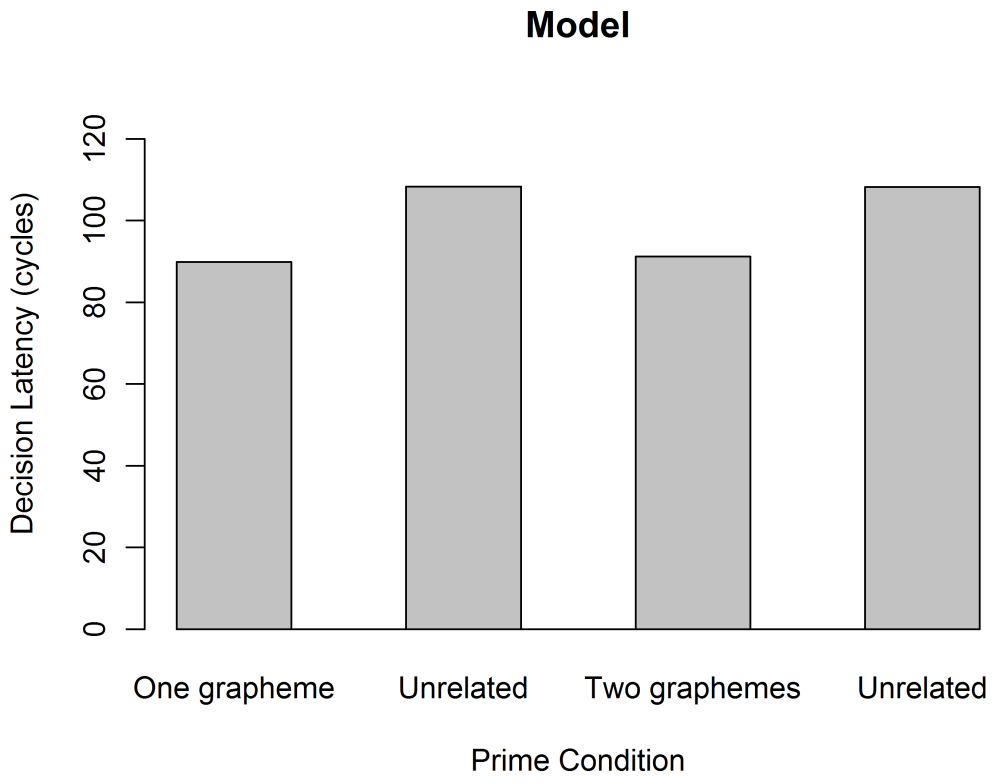


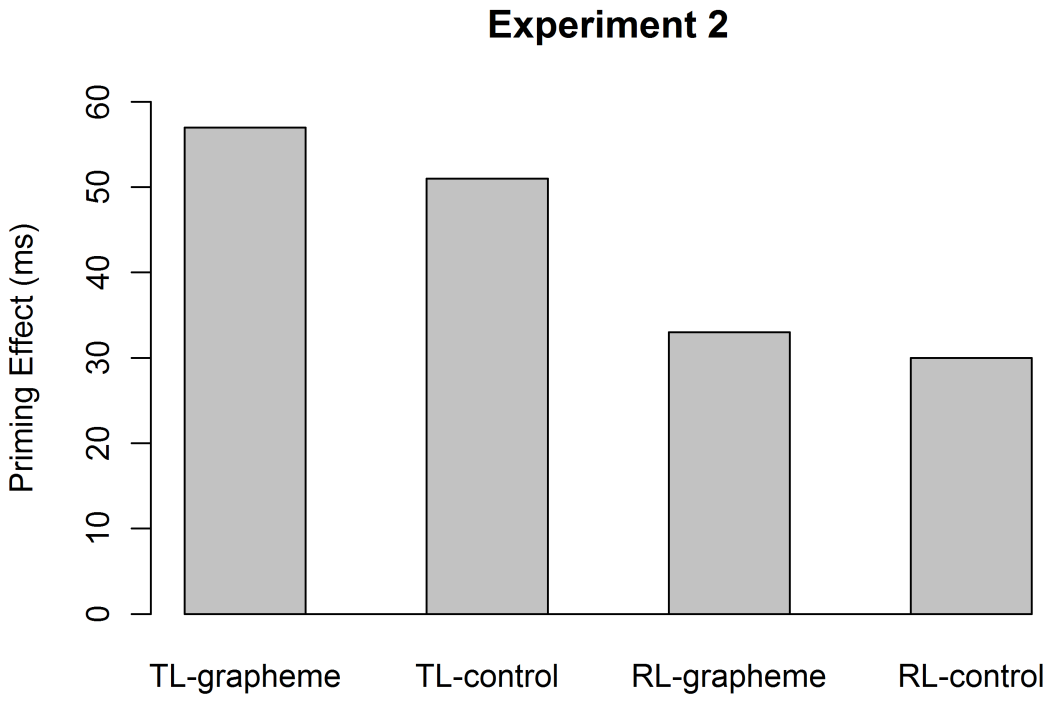

(a) A letter-input dual-route model

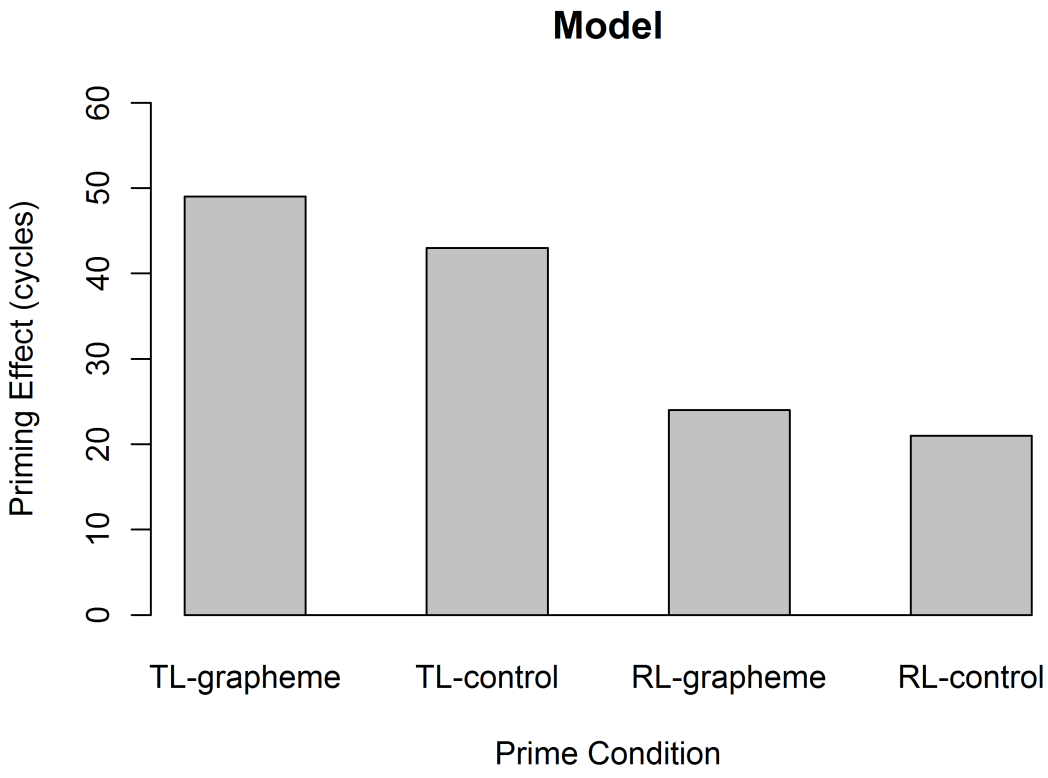



(b) A grapheme-input dual-route model


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) | | | Non-CH-Nonwords (Two Graphemes) | | |
|---|---|---|---|---|---|
| Target | TL Prime | RL Prime | Target | TL Prime | RL Prime |
| SECRETARIA | secertaria | senestaria | REBRADA | rebarda | retanda |
| TÉTRICO | tétirco | tébinco | LEBLETA | lebelta | letedta |
| INSCRIBIR | inscirbir | insnimbir | ISBROLLO | isborllo | isdonllo |
| LACRADO | lacardo | lasamdo | SUCRETO | sucerto | susento |
| SUBLEVAR | subelvar | sudetvar | URFLADO | urfaldo | urtabdo |
| RECLUTAR | recultar | rerudtar | LUFLETES | lufeltes | lutedtes |
| MEMBRANA | membarna | memdasna | PEBLAJE | pebalje | pedalje |
| ESTRIBO | estirbo | eslinbo | PEBLERO | pebelro | pedetro |
| MALTRATO | maltarto | mallasto | TOCLISMO | tocilsmo | tosifsmo |
| BÍBLICO | bíbilco | bíditco | CUNTRITO | cuntirto | cunfinto |
| ESCLAVO | escalvo | esnatvo | SORTRADO | sortardo | sorfando |
| MICROBIO | micorbio | misonbio | RUSCRIDIR | ruscirdir | rusnivdir |
| SECRETO | secerto | senesto | MUCRETO | mucerto | musento |
| DECRETO | decerto | desento | LUNCRITO | luncirto | lunsinto |
| REFRESCAR | referscar | retevscar | IRCLAMAR | ircalmar | irsatmar |
| LETRERO | leterro | lelesro | JECRADO | jecardo | jesando |
| ATRASO | atarso | alavso | ECRÓDATA | ecórdata | enósdata |
| RECLUSO | reculso | remudso | REBLAZO | rebalzo | refatzo |
| MEZCLADO | mezcaldo | meznatdo | TOCLUTAR | tocultar | tonudtar |
| ENCLAVE | encalve | ensadve | LEBLILLA | lebillla | leditlla |
| REFRANES | refarnes | refasnes | REMFLETO | renfelto | rentedto |
| INFLADO | infaldo | intabdo | UBRAZO | ubarzo | udanzo |
| ACRÓBATA | acórbata | anósbata | ERCREPAR | ercerpar | ersenpar |
| TABLILLA | tabillla | taditlla | CICRODIO | cicordio | cisonvio |
| TABLONES | tabolnes | tadotnes | TOBLEVAR | tobelvar | todetvar |
| DOBLAJE | dobalje | dodatje | TOBLADO | tobaldo | todafdo |
| ECLIPSE | ecilpse | esitpse | GÓBLICO | góbilco | góditco |
| TABLETA | tabelta | tadehta | SACLUSO | saculso | sanutso |
| RECLAMAR | recalmar | resatmar | PERTROJOS | pertorjos | perlonjos |
| DISFRACES | disfarces | disbances | GATRICO | gatirco | galinco |
| CICLISMO | cicilsmo | cisitsmo | PROFLADO | profaldo | protabdo |
| PANFLETO | panfelto | pantedto | SURBLORES | surbolres | surdotres |
| CHIFLADO | chifaldo | chibatdo | CABRINO | cabirno | cadisno |
| ENCLENQUE | encelnque | ensetnque | SUBRONES | subornes | sudosnes |
| CICLONES | cicolnes | cisotnes | ETRANO | etarno | elasno |
| ABRAZO | abarzo | adanzo | TACLIVE | tacilve | tanitve |
| NUTRIENTE | nutirente | nulivente | CECROARDAS | cecorardas | cesonardas |
| DISTRITO | distirto | dislimto | 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 |