CANADIAN PSYCHOLOGICAL ASSOCIATION
SOCIÉTÉ CANADIENNE DE PSYCHOLOGIE

Canadian Journal of Experimental Psychology /
Revue canadienne de psychologie expérimentale

ISSN: 1196-1961
2020, Vol. 74, No. 2, 92–110
http://dx.doi.org/10.1037/cep0000195

A Reexamination of Consonant–Vowel Differences in Masked Transposed Letter Priming Effects in the Lexical Decision Task

Huilan Yang and Stephen J. Lupker
University of Western Ontario

Most orthographic coding models are based on the assumption that the orthographic code does not distinguish between vowels and consonants and, therefore, those models predict no difference between vowel (cisano-CASINO) and consonant (caniso-CASINO) transposed-letter (TL) effects. The available data, however, do provide some evidence for a consonant–vowel distinction at the level of the orthographic code. Most centrally, masked priming lexical decision tasks, mainly carried out in Spanish, have shown priming from consonant TL primes (e.g., caniso) but not from vowel TL primes (e.g., cisano). The present experiments were an investigation of this pattern. Experiment 1, based on Schubert, Kinoshita, and Norris' (2018) stimuli which showed no consonant–vowel differences in an unprimed same-different task, also showed no consonant–vowel differences in masked TL priming effects in lexical decision showing, for the first time, a vowel TL priming effect in that task. Experiment 2, using Lupker, Perea, and Davis' (2008) Experiment 1a stimuli, also showed a small but significant vowel TL priming effect (a nonreplication of that experiment), while replicating the consonant TL priming effect that those authors originally reported. In Experiment 3, TL priming was again essentially unaffected by the consonant-vowel status of the letters involved as well as by target frequency, a variable on which the Experiment 1 and 2 stimuli differed. These results, supported by evoked response potential (ERP) results from other labs, suggest that consonant–vowel TL differences, when they do emerge in English, are likely are not due to the nature of the orthographic code.

Public Significance Statement
In order to understand the reading process in alphabetic languages, it is crucial to understand the different roles played by consonants versus vowels. Our findings suggest that consonant–vowel distinctions do not emerge at the level of orthographic coding, a conclusion consistent with most current theories of the early processes in reading.

Keywords: transposed letter priming, consonants and vowels, masked priming, lexical decision

In recent years, considerable research effort has been devoted to understanding the nature of the "orthographic code" (Grainger, 2018). The orthographic code is the code that is established early in the process of reading a word that represents both letter identities and their positions in that word. That code is assumed to then be used by readers as the means of accessing the higher-level information/representations (e.g., lexical, semantic) of the word being read.

As a result of the empirical work carried out over the past two decades, a number of models of orthographic coding (and lexical access based on the orthographic code) have emerged. One of the major drivers in the development of those models has been the report of transposed-letter (TL) effects. That is, the results from a number of experimental paradigms indicate that letter strings created by transposing two letters in a word (e.g., jugde) are treated as being more similar to their base words (i.e., JUDGE) than those in which those same two letters are substituted (e.g., substitution-letter [SL] strings like jupte; e.g., Perea & Lupker, 2003a, 2003b, 2004). Note also that TL effects emerge even when the transposed/substituted letters are not adjacent (e.g., caniso with the base word being CASINO; Perea & Lupker, 2004).

With respect to the majority of the models that have been proposed in an effort to explain orthographic coding (and, hence, TL effects), those models can generally be divided into two classes. One type of model, the "noisy position" models (Adelman, 2011; Davis, 2010; Gómez, Ratcliff, & Perea, 2008; Norris & Kinoshita, 2012; Norris, Kinoshita, & van Casteren, 2010), is based on the idea that while letter identities can be determined relatively quickly, those letters' positions in the code take longer to resolve. The other type of model, the "local-context" or "open-bigram" models (Grainger, Granier, Farioli, Van Assche, & Van

---

Huilan Yang and Stephen J. Lupker, Department of Psychology, University of Western Ontario.

This research was partially supported by Natural Sciences and Engineering Research Council of Canada Grant A6333 to Stephen J. Lupker. The raw data from all of the present experiments can be found at https://osf.io/t5r8d/?view_only=bad5843187194073a3ba43ae36a4b890

Correspondence concerning this article should be addressed to Huilan Yang or Stephen J. Lupker, Department of Psychology, University of Western Ontario, London, ON N6A 5C2, Canada. E-mail: yhuilan@uwo.ca or lupker@uwo.ca

Heuven, 2006; Grainger & Van Heuven, 2003; Schoonbaert & Grainger, 2004; Whitney, 2001; Whitney & Marton, 2013), is based on the idea that there is an intermediate level of representation between abstract letter units and word units, a level involving bigrams (a main purpose of which is to code the order of the letters in the presented string). Although considerable effort has now been made in trying to test between these models (e.g., Davis & Lupker, 2017; Lupker, Zhang, Perry, & Davis, 2015; Whitney, Bertrand, & Grainger, 2011), the contrast between models is not the focus of the present research. Rather, the specific focus is an examination of an assumption that all of these models make, the assumption that the orthographic code does not distinguish between vowels and consonants.

Although there have been a number of experimental paradigms used to investigate the nature of the orthographic code (and the role of vowels vs. consonants in the code), the most commonly used paradigm has been the masked priming lexical-decision task (LDT; Forster & Davis, 1984). In that task a forward mask is usually presented initially, followed by a brief (i.e., <70 ms) lower case prime and then an upper case word or nonword target. Because the prime and target are presented in the same location on the viewing screen, the target effectively backward masks the prime, preventing the participant from becoming aware of the prime's identity or, normally, even its existence. Nonetheless, orthographically similar primes (e.g., the nonword prime hoise for the target HOUSE) typically do produce shorter lexical decision latencies than orthographically dissimilar (i.e., "unrelated") nonword primes like brean.

The initial supposition was that this experimental paradigm would be ideal for investigating the nature of the orthographic code, as the size of the priming effect should document the similarity of the prime's and target's orthographic codes. Subsequently, however, it has been shown that the situation is a bit more complicated than first assumed due to the fact that other factors such as target neighborhood size (Davis & Lupker, 2006; Forster, Davis, Schoknecht, & Carter, 1987) and prime lexicality (i.e., word primes can produce inhibition rather than facilitation, Davis & Lupker, 2006; Segui & Grainger, 1990) affect the size of the priming effect. When factors of this sort are controlled, however, this experimental paradigm has been assumed to provide reliable information concerning the nature of the orthographic code.

Using that paradigm, there are now a number of demonstrations in the literature that TL primes are better primes than SL primes (e.g., Guerrera & Forster, 2008; Lupker, Perea, & Davis, 2008; Perea & Lupker, 2003a, 2003b, 2004). We refer to this difference as a "TL priming effect." Most central to the present investigation is an effect initially reported by Perea and Lupker (2004) in Spanish which suggests that the orthographic code makes a distinction between vowels and consonants. Specifically, whereas transposing two nonadjacent consonants (e.g., caniso-CASINO) produced a significant TL priming effect, transposing two nonadjacent vowels (e.g., cisano-CASINO) did not. Further, there are now three other papers showing the null priming effect for vowel TL primes in Spanish (Carreiras, Vergara, & Perea, 2009; Comesaña, Soares, Marcet, & Perea, 2016; Perea & Acha, 2009), although Carreiras, Vergara, et al. (2009) failed to find a significant interaction between consonant–vowel (C-V) status and priming ($F = 0.90$). Therefore, the published literature does provide at least some evidence for the conclusion that vowel TL primes are not effective primes, at least in Spanish.

The only reported examination of this issue in a language other than Spanish was by Lupker, Perea, and Davis (2008). In their Experiment 1a, involving English stimuli and, as in the Spanish studies, nonadjacent transpositions (e.g., caniso-CASINO, cisano-CANISO), they found a significant (24 ms) TL priming effect when the transposition involved two consonants and a nonsignificant (3 ms) TL priming effect when the transposition involved two vowels, paralleling the Spanish pattern. This C-V TL priming difference in this task and, specifically, the null effect using vowel transpositions is the main empirical focus of the present experiments.

There are, of course, other paradigms that have provided evidence for a C-V distinction that, potentially, implicate the orthographic coding process. There are also some orthographic coding models in the literature that do make a distinction between vowels and consonants (e.g., Berent & Perfetti, 1995; Caramazza & Hillis, 1990; Chetail & Content, 2012). For example, using an unprimed same-different task (a task in which participants must indicate whether two sequentially presented letter strings, the reference stimulus and the target, are the same or different), Chetail, Drabs, and Content (2014) and Chetail, Ranzini, De Tiège, Wens, and Content (2018) have shown that it is easier to classify TL nonwords as "different" from (the initial presentation of) their base word if the C-V structure (defined in terms of consonant and vowel clusters) is altered (theatre-THETARE) than if it is preserved (e.g., feature-FETAURE). A second, potentially, orthographic coding effect was reported by Perea and Lupker (2004), Lupker et al. (2008), Carreiras and Price (2008), and Schubert, Kinoshita, and Norris (2018). In an unprimed LDT, there was a larger difference between TL and SL nonwords (i.e., a TL effect) in the time to classify a letter string as a nonword when consonants were transposed than when vowels were transposed. (Unlike in the masked priming LDT experiments mentioned above, however, a TL effect for vowel TL nonwords was observed.)

On the other hand, there is also considerable evidence supporting the assumption that there are no C-V differences at the level of the orthographic code. Perea and Acha (2009), for example, failed to find a C-V TL difference in a masked priming same-different task, a task in which a masked prime is presented between the reference stimulus and the target. As another example, Colombo, Spinelli, and Lupker (2019) failed to find a difference between adjacent consonant-vowel transpositions and consonant-consonant transpositions in a masked priming LDT in either Italian or English. Additionally, although, as noted, Carreiras, Vergara, et al. (2009), Comesaña et al. (2016), and Perea and Acha (2009) have produced masked priming LDT data replicating Perea and Lupker's (2004) pattern, the only one of those experiments to collect Evoked Response Potential (ERP) data (Carreiras, Vergara, et al., 2009) produced ERP data inconsistent with that pattern. ERP techniques have the advantage of being able to provide temporal information concerning effects. What Carreiras, Vergara, et al. (2009) showed was that the C-V differences in an early time window where orthographic coding would be taking place (150–250 ms) favored the vowel TL manipulation. The results from two other studies investigating this issue using ERP data, although with slightly different experimental techniques (Carreiras, Vergara, & Perea, 2007; Vergara-Martínez, Perea, Marín, & Carreiras, 2011), showed virtually no differences between consonant and vowel TL manipulations in time windows before 400 ms. Vergara-Martínez et al. (2011) ultimately concluded in the abstract to their article "Differences between vowels and consonants regarding letter position assignment are discussed in terms of a later phonological level involved in lexical retrieval" (p. 105).

This conclusion that any C-V TL differences arise later in processing is supported by a number of other results. For example, using a boundary paradigm in which the parafoveal preview stimulus is either a TL or SL nonword, Johnson (2007) found a TL advantage on total fixation duration but no difference between consonant versus vowel manipulations for English readers. For Thai readers, Winskel and Perea (2013) found a larger TL effect for consonants, however, the effect was only in gaze duration (a measure of later processing), not in first or single fixation durations in spite of the fact that, in Thai, vowels play "a relatively subsidiary role in relation to consonants" (p. 119). In summary, therefore, it does not appear that there is an obvious explanation for why consonant TL nonwords produce a priming effect whereas vowel TL nonwords do not in a masked priming LDT, nor is there as yet a clear answer to the question of whether the orthographic code is sensitive to C-V differences.

The Present Research

Recently, Schubert et al. (2018), using the unprimed same-different task, have reported a result that directly relates to Perea and Lupker's (2004) C-V masked TL priming pattern. What Schubert et al. (2018) reported was that on trials when the reference stimulus and the target were different there was no C-V difference in rejection latency for the set of TL nonwords that they used in their Experiment 3. That is, when CHOCOLATE was the reference stimulus, although it was harder to reject TL nonword targets (i.e., CHOLOCATE) than SL nonword targets (e.g., CHOSORATE), the TL effects were the same size for consonant versus vowel letter transpositions. As Norris, Kinoshita, and colleagues (Kinoshita & Norris, 2009, 2010; Norris & Kinoshita, 2008) have argued, whether a masked prime is used in the task or not, the same-different task is performed based primarily on orthographic codes (although see Lupker, Nakayama, & Perea, 2015 and Lupker, Nakayama, & Yoshihara, 2018 for evidence that the task is not immune to phonological influences). If so, the results Schubert et al. (2018) observed would be orthographic coding phenomena. Those results can be taken to imply, therefore, that vowels and consonants, at least the vowels and consonant patterns involved in the words that those researchers used, are not coded differently.

Schubert et al.'s (2018) data would appear to present an interesting puzzle. If it is the case that: (a) their task indexes the nature of the orthographic code and (b) there are no differences between consonant and vowel TL effects for their stimuli, if those stimuli were to be used in a masked priming LDT experiment they should produce equivalent TL priming effects for vowel versus consonant transpositions. That is, either both the consonant and vowel TL primes will fail to produce a priming effect or both the consonant and vowel TL primes will show a TL priming effect. Either result would raise the question of why this particular set of stimuli failed to behave in the way Lupker et al.'s (2008) Experiment 1a stimuli behaved.

The present Experiment 1 was, therefore, an attempt to reexamine the C-V issue using Schubert et al.'s (2018) stimuli in a masked priming LDT. To jump ahead, a TL priming effect difference between consonants and vowels was not found in Experiment 1. Rather, for the first time, vowel transpositions produced a good size priming effect. Therefore, in Experiment 2, the question was whether the only masked priming LDT experiment done with English readers that produced a null priming effect for vowel transpositions (Lupker et al.'s, 2008, Experiment 1a) would replicate. That is, would those stimuli again produce a consonant TL priming effect but no vowel TL priming effect?

Finally, the contrast between Experiments 1 and 2 led to the proposal that the size of vowel TL priming effects may be a function of target frequency. That proposal was examined in Experiment 3.

Experiment 1

Method

Participants. Sixty undergraduate students from Western University received course credit for participation in this experiment. All were English native speakers and had normal or corrected-to-normal vision and no reading disorder. Before starting any of the three experiments reported in the present article, all participants signed a consent form.

Materials. The word stimuli in Experiment 1 were the nine-letter words reported as being used in Schubert et al.'s (2018) Experiment 3. The mean word frequency of the word targets (per million from SUBTLWF) is 4.50 (range: 0.02–140.67), their mean neighborhood size (N; Coltheart, Davelaar, Jonasson, & Besner, 1977) is 0.18 (range: 0–1), and their mean OLD20 value is 3.15 (range: 2.35–4.15). All these values were computed based on norms from the English Lexicon Project Database (Balota et al., 2007). Eighty multisyllabic nine-letter nonwords were also selected.

The "different" trials from Schubert et al.'s (2018) Experiment 3 provided four types of nonword primes for each word target: (a) a transposition involving two nonadjacent consonants (e.g., *specutale-SPECULATE*, the consonant-consonant transposed letter (CCTL) condition); (b) a substitution of the two consonants used in the CCTL condition with other consonants (e.g., specurane-*SPECULATE*, the consonant-consonant substituted letter (CCSL) condition); (c) a transposition involving two nonadjacent vowels (e.g., specalute-*SPECULATE*, the vowel-vowel transposed letter (VVTL) condition); (d) a substitution of the two vowels used in VVTL condition with other vowels (e.g., specolite-*SPECULATE*, the vowel-vowel substituted letter (VVSL) condition). The average position of first letter transposition/substitution was matched between the consonant ($M = 4.6$) and vowel ($M = 4.7$) conditions. The transposition/substitution never interrupted the first syllable. Note that the primes used in this experiment were taken directly from what was reported by Schubert et al. (2018) which meant that seven of the word targets were primed by primes that involved what appears to be a typographical error. Those seven targets were not included in the analyses.[1]

---

[1] Although it seemed unlikely that including (versus not including) these stimuli in the present experiment would affect the results for the remaining stimuli, they were included in Experiment 1 in order to match Schubert et al.'s (2018) experiment as closely as possible.

Every participant saw each word target and each nonword target once. For counterbalancing purposes, the word targets were divided into four sets, allowing the creation of four stimulus lists in which a given word target was primed by each of the four prime types in only one list. The nonword targets were also divided into four sets with each set primed by one of the four types of primes (CCTL, CCSL, VVTL, and VVSL). The assignment of prime types to nonword targets was not counterbalanced, however, and, thus, there was only one list of primes and nonword targets. The stimuli from all of the experiments reported in this article are listed in Appendix A.

Procedure. All participants were seated in a quiet room. The stimuli were presented using Eprime 2.0 software (Psychology Software Tools, Pittsburgh, PA; see Schneider, Eschman, & Zuccolotto, 2002). The stimuli were presented centrally on the screen in black with a white background. The sequence of stimuli on each trial was a row of 11 hashtags (###########) presented for 500 ms, a lowercase prime followed for 50 ms, and then an uppercase target replaced the prime, which remained on the screen for 2,000 ms or until the participant responded. All primes and targets were presented in 35-pt Courier New typeface. Eleven hashtags were used as a forward mask in order to cover the primes fully (some primes (e.g., pronemade) are longer than the others (e.g., attritube) due to the width of the particular letters in the prime). Response times were measured from the appearance of the target. Participants were asked to decide whether each presented letter string is a real English word or not. They were instructed to press the "J" button if the presented letter string is a word and the "F" button if it is a nonword. They were asked to respond as quickly and as accurately as possible. Stimulus presentation was randomized for each subject. The experimental blocks included 160 trials (80 words trials and 80 nonword trials) in Experiment 1. Sixteen practice trials preceded the experimental block. The experiments reported in the present article were approved by the Western University REB (Protocol # 104255).

Results

For the word trials, incorrect responses (10.1% of the data) and response times greater than 1,500 ms or more than three standard deviations from each participant's mean reaction time (RT; 1.2% of the data) were excluded from the latency analyses. In this and all subsequent experiments, the data from nonword targets were not analyzed due to the fact that the nonword targets were not counterbalanced across prime type. Linear mixed-effects models were used to analyze the latency and error rate data using the generalized linear mixed-effects model in the lme4 packages (Bates, Mächler, Bolker, & Walker, 2015; R Core Team, 2015). The syntax of those models for the experiments reported in the present article is contained in Appendix D.

Subjects and items were both included as random effects (Baayen, 2008; Baayen, Davidson, & Bates, 2008). The Gamma distribution was used to fit the raw RTs, with an identity link between fixed effects and the dependent variable (Lo & Andrews, 2015). The model was based on a 2 (Letter Type: Vowel, Consonant) × 2 (Transformation Type: TL, SL) design. Before running the model, R-default treatment contrasts were altered to sum-to-zero contrasts (Levy, 2014; Singmann & Kellen, 2017). The mean RTs and percent error rates from a subject-based analysis are shown in Table 1.

In the latency data, the main effect of letter type was significant, $ß = 4.735$, $SE = 1.963$, $z = 2.41$, $p = .016$, targets in the vowel conditions (669 ms) were processed slightly faster than targets in the consonant conditions (678 ms). The main effect of transformation type was also significant, $ß = 10.976$, $SE = 1.957$, $z = 5.61$, $p < .001$, targets following TL primes (663 ms) were processed faster than targets following SL primes (684 ms). There was, however, no interaction between those two factors, $ß = 0.09$, $SE = 1.917$, $z = 0.05$, $p = .963$. None of the effects approached significance in the error rate analysis (all $ps > .10$).

In order to quantify the evidence for our null interaction in the latency data, the "lmBF" and "compare" function of BayesFactor package with default JZS type was used to calculate the Bayes factor (Morey, Rouder, & Jamil, 2015), with the analysis being based on subject averaged latencies, because there are no Bayes factor packages implemented based on generalized linear mixed effects models. Model 1 with no interaction between letter type and transformation type was compared with Model 2 involving an interaction between these two factors. The typical cutoff for reasonable evidence for a model is a Bayes factor larger than 3 (Dienes, 2014). Model 1 (no interaction between letter type and transformation type) was compared with Model 2 (an interaction between these factors). Model 1 was the preferred model based on a calculated Bayes factor of 4.23 ± 0.04. Thus, there was reasonable evidence for a null interaction between letter type and transformation type.

What is also important to note that that the pattern of means provided no evidence at all for a potential interaction of the sort previously reported, that is, that consonant TL primes would produce priming while vowel TL primes would not, as the obtained priming effect was numerically larger with the vowel TL primes.

Discussion

Schubert et al.'s (2018) stimuli showed equivalent TL effects for vowel and consonant TL stimuli in a same-different task. The empirical question in Experiment 1 was what pattern would those stimuli show in a masked priming LDT? The answer is that, for the first time, a reasonably large vowel TL priming effect was found, an effect that has not been observed previously with either Spanish (Carreiras, Vergara, et al., 2009; Comesaña et al., 2016; Perea & Acha, 2009; Perea & Lupker, 2004) or, more relevantly, English

Table 1
Mean Lexical Decision Latencies (RTs in Milliseconds) and Standard Deviations (in Parentheses) as Well as Percent Error Rates in for the Word Targets in Experiment 1

	Consonant		Vowel	
Transformation type	RT	%E	RT	%E
TL	669 (105)	8.6	657 (92)	9.0
SL	687 (96)	10.2	682 (104)	8.6
Priming	18	1.6	25	−.4

Note. The overall mean RT and error rate of the nonword targets were 766 ms and 8.5%, respectively.

(Lupker et al., 2008) readers. Instead, none of those masked priming experiments showed any evidence of vowel TL priming.

Note that the pattern of results from Experiment 1 is quite consistent with virtually all the orthographic coding models mentioned earlier as those models make no distinction between vowels and consonants. Therefore, virtually all of them would predict no C-V TL priming interaction in either Experiment 1 or in the previous investigations. This pattern of results does, however, leave us with the empirical puzzle created by the contrast between Experiment 1 and Lupker et al.'s (2008, Experiment 1a) data. Experiment 2, therefore, was a reexamination of this issue by attempting to replicate that experiment, the one English experiment reported in the literature contrasting vowel and consonant TL priming effects in a masked priming LDT.

Experiment 2

Method

Participants. Seventy-two undergraduate students from Western University received course credit for participating in this experiment. All were English native speakers and had normal or corrected-to-normal vision and no reading disorder.

Materials. The stimuli were the same as those listed in Lupker et al.'s (2008) Experiment 1a. The targets were 80 multisyllabic words with a mean word length of 7.25 letters (range: 6–9), a mean word frequency (per million from SUBTLWF) of 14.3 (range: 0.29–101.96), a mean Coltheart, Davelaar, Jonasson, and Besner (1977) N of 0.34 (range: 0–2), and a mean OLD20 of 2.55 (range: 1.7–3.7). All these values were derived from norms in the English Lexicon Project Database (Balota et al., 2007). Eighty multisyllabic nonwords that were six to nine letters long ($M = 7.21$ letters) served as nonword targets.

The manipulation of prime type was the same as in the present Experiment 1. Four types of nonword primes (CCTL, CCSL, VVTL, and VVSL) had been created by Lupker et al. (2008) for each word target with all transpositions and substitutions involving nonadjacent letter positions. The average position of the first letter of the transposition/substitution was matched between the consonant ($M = 3.1$) and vowel ($M = 3.1$) conditions. The other manipulations were the same as in Experiment 1.

Procedure. The procedure was the same as in Experiment 1 except that the forward mask involved 10 hashtags due to the lengths of the primes and targets. Ten hashtags were used here instead of six hashtags, the number reported as being used in Lupker et al.'s (2008) Experiment 1a, in order to fully cover the primes (only four 9-letter words are included and, because of the letters they contained, they were fully covered by 10 hashtags). The experimental block included 160 trials (80 word trials and 80 nonword trials).

Results

For the word targets, one target was excluded from the data analysis, due to the fact that there was a typo in one of its primes. Response times longer than 1,500 ms or more than three standard deviations from each participant's mean RT (2.0% of the data) and incorrect responses (4.7% of the data) were excluded from the latency analyses. The esmeans package was used for post hoc analyses (Lenth, 2018). The model was based on a 2 (Letter Type: Consonant, Vowel) × 2 (Transformation Type: TL, SL) design. The other details were the same in Experiment 1. The mean RTs and percent error rates from a subject-based analysis for the word targets are shown in Table 2.

In the latency data, the main effect of letter type was significant, ß = 3.217, *SE* = 1.399, $z = 2.30$, $p = .022$. Targets in the vowel conditions (589 ms) were responded to slightly faster than targets in the consonant conditions (595 ms). The main effect of transformation type was also significant, ß = 9.146, *SE* = 1.406, $z = 6.51$, $p < .001$, as targets following TL primes (583 ms) were processed faster than targets following SL primes (602 ms). There was also a significant interaction between those two factors, ß = 3.245, *SE* = 1.383, $z = 2.35$, $p = .019$. In the post hoc analysis, for the consonant condition, latencies following TL primes were significantly faster (27 ms) than latencies following SL primes, ß = 24.8 *SE* = 3.95, $z = 6.28$, $p < .001$. In the vowel condition, the TL primes also led to significantly faster latencies (12 ms) than the SL primes, ß = 11.8, *SE* = 3.94, $z = 2.994$, $p = .003$. None of the effects approached significance in the error rate analysis (all *p*s > .10).

As noted by one of the reviewers, the outlier trimming procedure used here was slightly different than that used in Lupker et al.'s (2008) Experiment 1a. In that analysis, latencies less than 1,500 ms that were more than three standard deviations from the participant's mean were not excluded. Therefore, the present data were also analyzed using Lupker et al.'s (2008) procedure. For word trials, incorrect responses (4.7% of the data) and response times longer than 1500 ms (0.5% of the data) were removed from the latency analysis. In the latency data, the main effect of letter type was significant, ß = 3.437, *SE* = 1.602, $z = 2.15$, $p = .032$. The main effect of transformation type was also significant, ß = 10.095, *SE* = 1.571, $z = 6.43$, $p < .001$. There was also a significant interaction between those two factors, ß = 3.254, *SE* = 1.563, $z = 2.08$, $p = .037$. In the post hoc analysis, for the consonant condition, latencies following TL primes were significantly faster (29 ms) than latencies following SL primes, ß = 26.7 *SE* = 4.45, $z = 6$, $p < .001$. In the vowel condition, the TL primes also led to significantly faster latencies (13 ms) than the SL primes, ß = 13.7, *SE* = 4.41, $z = 3.102$, $p = .002$.

We also quantified the evidence for our interaction in the latency data in Experiment 2 by calculating the relevant Bayes factors. Model 1 with no interaction between letter type and transformation type was compared with Model 2 with an interaction between these two factors. The contrast between these two models based on the first trimming method produced a Bayes

Table 2
Mean Lexical Decision Latencies (RTs in Milliseconds) and Standard Deviations (in Parentheses) as Well as Percent Error Rates for Word Targets in Experiment 2

	Consonant		Vowel	
Transformation type	RT	%E	RT	%E
TL	582 (85)	4.1	583 (87)	4.6
SL	609 (91)	5.6	595 (90)	4.4
Priming	27	1.5	12	−.2

Note. The overall mean RT and error rate of the nonword targets were 700 ms and 8.5%, respectively. RT = reaction time; TL = transposed-letter; SL = substitution letter.

factor of 0.84 ± 0.04. The contrast between these two models based on the second trimming method produced a Bayes factor of 1.11 ± 0.05. These results would seem to contrast somewhat with the ANOVA results. That is, these analyses do not provide any real support for the conclusion that there was an interaction between letter type and transformation type in spite of the fact that the consonant TL priming effect was approximately 14 ms larger than the vowel TL priming effect.

Discussion

The question in Experiment 2 was would the pattern reported by Lupker et al. (2008) of a sizable TL priming effect for consonants (24 ms in that article) and no TL priming effect for vowels (3 ms) replicate? The results of Experiment 2 replicated the consonant TL priming effect reported in Lupker et al.'s (2008) Experiment 1a. The results for the vowel TL priming effect (a significant 13 ms) did not. Rather, for now a second time, a significant vowel TL priming effect was produced with English stimuli.

The reason for the failed replication isn't clear. The only obvious methodological difference between the present procedure and that in the 2008 article was the length of the forward mask. In the 2008 version of the experiment, it was reported that a mask consisting of only six hashtags was used whereas the forward mask consisted of 10 hashtags in the present version. Therefore, if anything, one might imagine that the mask in the present experiment would have been more effective, making those primes more difficult to process and, hence, producing a smaller priming effect. That result is, of course, the opposite of what was observed.

One other (nonmethodological) difference between Experiment 2 and Lupker et al.'s (2008) Experiment 1a was that the latencies in the vowel conditions were approximately 50 ms faster in the present Experiment 2. It's somewhat difficult to draw any conclusions based on this pattern due to the fact that the two experiments were run in different labs and, therefore, on different equipment and with different participant populations (Lupker et al.'s, 2008, Experiment 1a was run at the University of Bristol). One could, nonetheless, entertain the hypothesis that vowel TL priming effects only emerge when the targets can be processed relatively rapidly. Such a hypothesis would be challenged, however, by the fact that the latencies in the present Experiment 1, in which a sizable vowel TL priming effect was obtained, were approximately 50 ms longer than those in Experiment 2 in which a somewhat smaller vowel TL priming effect was obtained. That hypothesis will also be challenged by the results of the present Experiment 3 in which the vowel TL priming effect was slightly larger for the more slowly processed low frequency targets than for the high frequency targets.

What was consistent with Lupker et al.'s (2008) original report, however, was that the interaction did reach significance (although the Bayes factor analysis failed to provide conclusive evidence either for or against the interaction), regardless of the difference in the lengths of the forward masks. That pattern suggests that, at least for these stimuli, the consonant TL priming effect is stronger than the vowel TL priming effect. More centrally, however, the pattern that seems to be emerging is that vowel TL primes do have some ability to prime in English, in contrast to the pattern reported in the Spanish language experiments.

Experiment 3

Experiment 3 had two goals. The first was to use an entirely new set of (English) stimuli in an attempt to once again examine whether there is a vowel TL priming effect. The second was to investigate the interactive patterns in Experiments 1 and 2. In Experiment 1, the TL priming effects for consonants and vowels were statistically equal with the vowel priming effect actually being 7 ms larger. In Experiment 2, the pattern was significantly reversed with the consonant TL priming effect being 15 ms larger than the vowel TL priming effect. One thing to note about the contrast between Experiments 1 and 2, however, is that the targets were somewhat higher in frequency in Experiment 2. In fact, some of the targets in Experiment 1 may have been unfamiliar to our participants. One reasonable hypothesis is that these TL priming effects are affected by target frequency. Experiment 3 involved a new set of prime-target pairs to allow an evaluation of this idea. High and low frequency targets were selected and were primed by each of the four types of primes used in Experiments 1 and 2. If target frequency matters in a way suggested by the results of Experiments 1 and 2, we may obtain a null interaction with the low frequency targets and a significant interaction with the high frequency targets.

Method

Participants. Forty-four undergraduate students from Western University received course credit for participating in this experiment. All were English native speakers and had normal or corrected-to-normal vision and no reading disorder.

Materials. The targets were 80 multisyllabic high frequency words and another 80 multisyllabic low frequency words. The 80 multisyllabic high frequency words have a mean word length of 7.4 letters (range: 6–9), a mean word frequency (per million from SUBTLWF) of 84.6 (range: 31.37–383.39), a mean Coltheart et al. (1977) N of 0.33 (range: 0–3), and a mean OLD20 of 2.75 (range: 1.7–4.2). The 80 multisyllabic low frequency words have a mean word length of 7.7 letters (range: 6–9), a mean word frequency (per million from SUBTLWF) of 2.11 (range: 0.04–5.69), a mean N of 0.22 (range: 0–2), and a mean OLD20 of 2.77 (range: 1.85–3.85). One-hundred and 60 multisyllabic nonwords that were six to nine letters long (M = 7.9 letters) served as nonword targets. These nonwords have a mean N of 0.43 (range: 0–2). All these values were based on norms from the English Lexicon Project Database (Balota et al., 2007).

The manipulation of prime type for high frequency words and low frequency words were the same as in the present Experiments 1 and 2. Four types of nonword primes (CCTL, CCSL, VVTL, and VVSL) were created for each word target with all transpositions and substitutions involving nonadjacent letter positions. The average position of the first letter of the transposition/substitution was matched between the consonant (M = 3.3) and vowel (M = 3.3) conditions. The other manipulations were the same as in Experiments 1 and 2.

Procedure. The procedure was the same as in Experiments 1 and 2.

Results

For word targets, incorrect responses (6.4% of the data) and response times greater than 1,500 ms or more than three standard deviations from each participant's mean RT (2.1% of the data) and were excluded from the latency analyses. The model was based on a 2 (Frequency: High, Low) × 2 (Letter Type: Consonant, Vowel) × 2 (Transformation Type: TL, SL) design. The mean RTs and percent error rates from a subject-based analysis for the word targets are shown in Table 3.

In the latency data, the default model failed to converge even when the model was restarted. We then proceeded to rerun the model using all available optimizers. The results reported are the results from the BOBYQA optimizer which is the procedure that tends to be best able to produce convergence. The main effect of letter type was significant, ß = 4.583, *SE* = 1.441, $z = 3.18$, $p = .001$. Targets in the vowel conditions (612 ms) were processed slightly faster than targets in the consonant conditions (622 ms). The main effect of transformation type was also significant, ß = 9.805, *SE* = 1.44, $z = 6.81$, $p < .001$, as targets following TL primes (607 ms) were processed faster than targets following SL primes (627 ms). The main effect of frequency was also significant, ß = −39.926, *SE* = 4.777, $z = -8.36$, $p < .001$, as high frequency words (580 ms) were processed faster than low frequency words (654 ms). Crucially, there was no hint of any interactions between any of those factors (all *p*s > .10).

In the error rate data, the default model converged when the model was restarted. The main effect of letter type was not significant, ß = −0.001, *SE* = 0.067, $z = -0.02$, $p = .983$. The main effect of transformation type was significant, ß = −0.149, *SE* = 0.067, $z = -2.22$, $p = .027$, as targets following TL primes (5.4%) produced fewer errors than targets following SL primes (6.6%). The main effect of frequency was also significant, ß = 0.723, *SE* = 0.12, $z = 6.03$, $p < .001$, as high frequency targets produced fewer errors (2.4%) than low frequency targets (9.7%). None of the two-way interactions approached significance in the error rate analysis (all *p*s > .10), however, the three-way interaction did reach significance, ß = −0.148, *SE* = 0.068, $z = -2.19$, $p = .028$ due to the fact that the largest priming effect in the error rate data (2.6%) was found in the low frequency vowel condition whereas the smallest priming effect was found in the high frequency vowel condition (−0.2%).

Table 3
Mean Lexical Decision Latencies (RTs in Milliseconds) and Standard Deviations (in Parentheses) as Well as Percent Error Rates for the Word Targets in Experiment 3

	Consonant		Vowel	
Transformation type	RT	%E	RT	%E
High frequency words				
TL	576 (81)	1.5	568 (67)	2.5
SL	596 (74)	3.2	583 (69)	2.3
Priming	20	1.7	15	−.2
Low frequency words				
TL	645 (90)	9.5	639 (87)	8.2
SL	671 (105)	10.2	659 (102)	10.8
Priming	26	.7	20	2.6

Note. The overall mean RT and error rate of the word targets were 760 ms and 11%, respectively. RT = reaction time; TL = transposed-letter; SL = substitution letter.

A Bayes factor analysis was again undertaken on the latency data in an effort to evaluate the strength of the evidence for both the three-way interaction and the two-way interaction between letter type and transformation Type. Initially, Model 1 (based on no interaction between letter type, transformation type, and frequency) was compared with Model 2 (a three-way interaction). Model 1 (no three-way interaction) was strongly supported, with a Bayes factor of 657 ± 0.07. In the second analysis, Model 1 (based on no interaction between letter type and transformation type) was compared with Model 2 (a two-way interaction). Model 1 was supported, with a Bayes factor of 3.46 ± 0.05, providing reasonable evidence in favor of a null interaction.

Discussion

The results of Experiment 3 support two conclusions. First, they show, once again, that, in English, it is quite possible to produce masked vowel TL priming effects in an LDT and, further, that vowel TL priming effects can be as large as consonant TL priming effects. As mentioned, this result is fully consistent with virtually all those models of orthographic coding that do not explicitly distinguish between consonants and vowels. The results of Experiment 3 also indicate that TL priming effects seems to arise independent of the frequency of the targets. Therefore, it seems unlikely that the apparent difference between the vowel TL priming effects in Experiment 1 and 2 was caused by a frequency difference between the targets used in those two experiments.

What the results from the present experiments are not consistent with are the results of Lupker et al.'s (2008) Experiment 1a in which vowel TL primes produced only a nonsignificant 3-ms priming effect (and, of course, all the Spanish experiments that also showed a null vowel TL priming effect). Essentially, the results of Experiments 1–3 appear to support the conclusion that the one report of a null vowel TL priming effect in English was likely a Type II error. What needs to be kept in mind, of course, is that even in Experiment 2, the vowel TL priming effect with that particular set of stimuli was not large (12 ms). Therefore, the power to detect a true effect of that size in Lupker et al.'s (2008) Experiment 1a was probably less than optimal.

General Discussion

Three experiments involving letter transpositions were performed in order to provide a further examination of the role of letter type in masked TL priming effects in English LDTs. The results of Experiment 1, using Schubert et al.'s (2018) Experiment 3 stimuli, showed no C-V difference in TL priming effects and, for apparently the first time, a vowel TL priming effect in adults when using English word targets. A significant vowel TL priming effect difference also emerged in Experiment 2 using the stimuli from Lupker et al.'s (2008) Experiment 1a, however, that effect was smaller than the effect in the consonant TL condition. The results in Experiment 3 also indicated that TL priming effects can be found with vowel TL primes in English (and can be equivalent in size to effects with consonant TL primes) as well as showing that these effects seem to arise independently of the frequency of the targets. Taken together, our findings suggest that, in English, C-V

TL priming differences and null vowel TL priming effects are not the norm in the masked priming LDT and, therefore, any effects of this sort are not likely due to something intrinsic to the nature of the orthographic code for English readers. Although the present data pattern is different from the behavioural data found in parallel experiments in Spanish (Carreiras, Vergara, et al., 2009; Comesaña et al., 2016; Perea & Acha, 2009), our conclusion is consistent with the (Spanish) ERP results examining C-V TL differences (e.g., Carreiras et al., 2007; Carreiras, Vergara, et al., 2009; Vergara-Martínez et al., 2011), with Perea and Acha's (2009) results in the masked priming same-different task using Spanish stimuli, with Johnson's (2007) parafoveal preview data in English and with many of the current models of orthographic coding, specifically, those that do not make a distinction between consonants and vowels (Adelman, 2011; Davis, 2010; Gómez et al., 2008; Grainger et al., 2006; Grainger & Van Heuven, 2003; Norris & Kinoshita, 2012; Norris et al., 2010; Schoonbaert & Grainger, 2004; Whitney, 2001; Whitney & Marton, 2013). Nonetheless, a number of puzzles remain.

What Is the Locus of Consonant–Vowel Differences in Other Tasks?

If the orthographic code does not distinguish between consonants and vowels, what is the explanation of the C-V differences found in the literature, particularly differences found in those studies using experimental tasks other than the masked priming LDT? For example, in French unprimed same-different tasks, Chetail et al. (2014) and Chetail et al. (2018) reported that TL nonwords created by changing the number of C-V clusters in the reference stimulus were easier to classify as "different" than nonwords maintaining the reference stimulus's C-V structure (e.g., poivrer as a reference stimulus, POVIRER vs. POIRVER as "different" targets). Based on these results the authors suggested that the C-V structure of letter strings (defined in terms of vowel and consonant clusters) influences processing at an early level.

Those experiments certainly do support the idea that the C-V structure has some influence on the nature of memory representations involved in the matching process in the unprimed same-different task. Further, those representations, presumably, do have some orthographic basis. That general idea of C-V differences is reinforced by the fact that there do appear to be such differences when English TL nonwords are used in an unprimed LDT (Lupker et al., 2008; Schubert et al., 2018), with consonant TL nonwords creating a larger TL effect than vowel TL nonwords. However, what needs to be noted is that both the unprimed same-different task and the unprimed LDT are based on the process of comparing a clearly visible stimulus to a memory representation rather than directly examining the nature of the early processing of that stimulus. Thus, it is far from obvious that the representation that participants use when making decisions in those experiments is the same as the one being investigated here (i.e., what we have been calling the orthographic code, that is, the code created early in the processing of a presented word which then spurs further processing). Indeed, although a full analysis of the tasks showing a C-V difference will not be presented here, the above characterization would appear to apply in most instances. Hence, results from those types of tasks do not appear to pose a serious challenge to the conclusion that the orthographic code does not distinguish between consonants and vowels.

The question of where any C-V differences do come from when they are observed, however, remains. One hypothesis that should be seriously considered is that those differences are phonologically based effects and that they arise at a level beyond the orthographic-coding level (Frankish & Barnes, 2008; Frankish & Turner, 2007; Vergara-Martínez et al., 2011). Certainly, it has been clear for some time now that phonology can play an important role in how people determine whether a letter string matches a stored lexical representation, as witnessed by the existence of homophone effects (Pexman, Lupker, & Jared, 2001; Pexman, Lupker, & Reggin, 2002; Rubenstein, Lewis, & Rubenstein, 1971) and pseudohomophone effects (Berent, 1997; Gibbs & Van Orden, 1998; Grainger & Ferrand, 1996; Parkin & Ellingham, 1983; Stone & Van Orden, 1993) in unprimed LDTs. There is also evidence that same-different judgments, which, as noted, involve a contrast between a visible stimulus and a representation held in short-term memory, are made, at least to some degree, on the basis of phonological codes (Lupker et al., 2015, 2018; although see Kinoshita & Norris, 2009, for a counterargument). In fact, it would seem reasonable that on trials in which the decision is difficult (i.e., deciding that the target CHOCALOTE and the reference stimulus CHOCOLATE do not match), participants would recruit any information they could in order to aid their decision-making process. Phonological information may be quite useful in aiding decision-making processes if, for no other reason, phonological information may be easier to maintain in memory while those processes are unfolding.

Why Are There, Nonetheless, Some Consonant–Vowel Differences in Masked Priming LDTs?

There are a number of masked priming LDT experiments in the literature, not involving TL manipulations, which do show C-V differences. For example, Duñabeitia and Carreiras (2011) showed that, in Spanish subset priming, the consonants in target words (e.g., nml-ANIMAL, "consonant-preserving primes") were effective primes while subset primes created from the vowels (e.g., aia-ANIMAL, "vowel-preserving primes") were not. Carreiras, Gillon-Dowens, et al. (2009), using Spanish stimuli, showed that slightly delaying two consonants in a masked identity prime was more detrimental than slightly delaying two vowels. With French stimuli, New, Araújo, and Nazzi (2008) showed that primes created by preserving only the two consonants in four-letter words (e.g., dovu-DIVA) were effective primes whereas primes created by preserving only the two vowels (e.g., rifa-DIVA) were not. New and Nazzi (2014) using both four- and six-letter (French) word targets, although failing to replicate the significant consonant-preserving priming effect, showed that the vowel-preserving priming effect was actually inhibitory (i.e., there was a clear C-V difference).

In fact, even in the present experiments, although the results support the claim that vowel TL priming effects exist in English, the consonant and vowel manipulations did not inevitably produce exactly the same results. Note, for example, that, overall, the primes in which the vowels were manipulated (e.g., cisano and cesuno, which are both consonant-preserving primes) produced slightly (6–10 ms), but significantly, shorter latencies than primes in which the consonants were manipulated (i.e., caniso and caviro, which are vowel-preserving primes). This pattern, which is consistent with New et al.'s (2008) and New and Nazzi's (2014) results, was not found, however, in the (Spanish and English) studies that prompted the present research (i.e., Carreiras, Vergara, et al., 2009; Comesaña et al., 2016; Perea & Acha, 2009; Perea & Lupker, 2004). All of those studies found that the consonant TL primes (e.g., caniso), which are vowel-preserving primes, were the most effective primes. Finally, note that Experiment 2 (the reexamination of Lupker et al.'s, 2008, Experiment 1a) provided evidence that, in some situations, there can be C-V TL priming differences (the significant interaction), in contrast to the patterns in the present Experiments 1 and 3 which do not show an interaction. In essence, the overall pattern of results does indicate that performance in masked priming LDTs can be affected to at least some degree by the C-V status of the letters in the prime. If the orthographic code does not distinguish between consonants and vowels, an alternative explanation is needed.

What is likely the most viable explanation would seem to be one derived from Duñabeitia and Carreiras's (2011) lexical constraint hypothesis. This hypothesis is based on the idea that a prime's impact on target processing is a reflection of which lexical representations the prime activates and how the activation process then proceeds rather than any C-V differences in the structure of the orthographic code. Essentially, the general idea is that the more supportive/informative the prime is with respect to the target, the more effective the prime will be. The existence of masked orthographic priming effects in the first place (e.g., sudge-FUDGE) indicates that primes activate the lexical representations of similarly spelled words. Importantly, some primes (e.g., fudpe) will activate fewer representations than others (e.g., sudge), allowing activation to be more concentrated on those fewer representations. When an orthographically related target (e.g., FUDGE) is presented, the ultimate priming effect will then be a function of which and how many targets are activated (e.g., see Davis & Lupker's, 2006, and Forster, Davis, Schoknecht, and Carter's (1987), results when examining neighborhood size effects in masked orthographic priming experiments).

The priming effect size will also be a function of the way in which the other activated representations compete with that of the actual target, in the sense that that pattern will be somewhat different when the number of activated competitors is small versus large. Indeed, the contrast between nonword (e.g., sudge-FUDGE) versus word (judge-FUDGE) primes, that is, nonword primes produce facilitation and word primes produce either inhibition or a null effect (Davis & Lupker, 2006; Segui & Grainger, 1990), indicates that the nature of the lexical competition process is important as well as indicating that that process is affected by both which lexical representations get activated by the prime and to what degree they are activated.

At present, however, it is far from clear how theorists should characterize lexical activation patterns. For example, the research on superset (zfudge-FUDGE; Lupker, Zhang, et al., 2015; Van Assche & Grainger, 2006) and subset (nml-ANIMAL) priming (e.g., Duñabeitia & Carreiras, 2011; Grainger et al., 2006) indicates that primes do not have to be the same length as their targets in order to activate the lexical representations of those targets. However, we do not know the limits of such effects (e.g., Would superset primes tregfudge or fudgetreg active the lexical representation for FUDGE?). Further, there is the question of whether primes sharing only a few letters with their targets (e.g., fapte-FUDGE) activate the lexical representation of those targets to any degree. Although there is no evidence for priming of this sort in the conventional masked priming task, effects of this sort can be obtained using the sandwich priming paradigm (Lupker & Davis, 2009).

What we do know, however, is that in alphabetic languages consonant are, on average, more constraining/informative than vowels in terms of what targets are likely to get activated (e.g., Duñabeitia & Carreiras, 2011). That is, the activation pattern created by presenting the three consonants in ANIMAL (i.e., nml) will activate fewer additional words than the presentation of the three vowels (i.e., aia). Therefore, the activation pattern in the lexicon created by consonant-preserving primes is likely to be more supportive of the target, on average, than the activation pattern created by vowel-preserving primes. As a result, the more typical pattern would likely be larger priming effects from consonant-preserving primes. Crucially, however, this can only be an "on average" statement until a better understanding of the nature of lexical activation patterns has been achieved.

Essentially then, Duñabeitia and Carreiras's (2011) account would seem to provide a reasonable explanation of many of the C-V differences found in the literature. What also has to be stated again, however, is that their account does not fare well in attempting to account for the data on C-V differences in TL priming effects, the subject of the present investigation. In those types of experiments, the vowel condition primes (i.e., cisano-CASINO and cesuno-CASINO) are the primes that preserve the consonants in their appropriate positions and, therefore, in line with Duñabeitia and Carreiras's (2011) account, those primes should produce the fastest latencies (with, the TL prime, cisano, producing the overall fastest latency). In the present data, this prediction was upheld in Experiments 1 and 3, although not in Experiment 2. As noted just above, however, results in the previous literature (Carreiras, Vergara, et al., 2009; Comesaña et al., 2016; Perea & Acha, 2009; Perea & Lupker, 2004) provide no support for this prediction. Therefore, although there is clearly merit to Duñabeitia and Carreiras's (2011) lexical constraint proposal in that it can explain many of the C-V differences in masked priming LDTs, it does not seem like it will provide an explanation of the C-V TL priming patterns.

The Spanish–English Contrast

The one obvious remaining question is why does it not appear to be possible to get vowel TL priming in masked priming LDTs in Spanish? As noted previously, there are four studies in the literature showing no priming from vowel TL nonwords in Spanish LDTs (Carreiras, Vergara, et al., 2009; Comesaña et al., 2016; Perea & Acha, 2009; Perea & Lupker, 2004). Meanwhile, the only English study showing a similar lack of an effect, Experiment 1a in Lupker et al. (2008), has now failed to stand up to replication. Coupled with the results from the present Experiments 1 and 3, the results of this failed replication in the present Experiment 2 indicate that vowel TL nonwords do produce priming in an LDT in English. Essentially, therefore, all the experiments showing a null impact of vowel TL nonwords (in comparison with vowel SL nonwords), when presented as primes in an LDT, have been carried out in Spanish. Could the Spanish–English difference reflect a different pattern of lexical activation in the two languages, a basic difference in the orthographic coding processes in the two languages or might it be due to some other factor?

Of these three possibilities (and following from the previous discussion of the source of C-V differences in other paradigms), the idea that many C-V TL differences are due to the involvement of phonological codes would appear to have the most potential for trying to understand why vowel TL primes can be effective primes in English, but not in Spanish. Although there are a number of English–Spanish differences (e.g., Spanish is a very syllabically based language even though it is written in an alphabetic script), one very clear language difference is that the grapheme-phoneme correspondences for vowels are more inconsistent in English than in Spanish (Brown & Besner, 1987; Carr & Pollatsek, 1985; Kessler & Treiman, 2001). Hence, phonological coding is likely more rapid in Spanish than in English. Presumably, this fact could allow phonology to play a larger role in a Spanish LDT.

So, the question becomes, what is it about the nature of phonological processing that is causing the masked priming provided by vowel TL nonwords in the Spanish same-different task (Perea & Acha, 2009) and in English LDTs (although see Lupker et al., 2008) to not appear in Spanish LDTs? That is, can an explanation for this difference be framed based on some phonological principles? One such argument could be based on Comesaña et al.'s (2016) claim that consonant transpositions seem to preserve more of the phonological information of the base word than vowel transpositions (e.g., there is a difference between the similarity of a consonant TL prime and its base word, e.g., "relovution-revolution", vs. a vowel TL prime and its base word e.g., "revulotion-revolution"; see also, Carreiras & Price, 2008). Specifically, consonant transpositions seemed to preserve more of the prosodic pattern (e.g., intonation and rhythm) of the base word in comparison with vowel transpositions. Therefore, if phonological information is available quite rapidly in Spanish, one would expect that consonants would be better able to generate priming than vowels. As a result, the impact of phonological information in masked priming LDTs in Spanish would have the potential to explain why Spanish readers produce consonant TL priming effects but not vowel TL priming effects.

Comesaña et al.'s (2016) argument, however, would need to be that not only do phonological representations not produce priming from vowel TL primes but, in fact, phonological information somehow diminishes whatever priming is available as a function of orthographic similarity. That is, it would need to explain why Perea and Acha's (2009) masked priming effects for vowel TLs in the same-different task are reduced to zero in LDTs. Potentially, the argument could be extended to include a mechanism of inhibition as suggested by New and Nazzi (2014) who did produce some evidence of inhibition from primes sharing vowels with their targets (e.g., rifa-DIVA) in their longer SOA conditions. At present, however, it is unclear how a (inhibition) mechanism of this sort would work.

As an alternative, one could argue that TL priming effects in Spanish LDTs are, themselves, entirely phonologically based (i.e., orthography plays no role at all) and, further, that vowel TL primes are simply ineffective at producing phonological priming effects in Spanish (potentially building on the presumably different impact of vowels vs. consonants on the prosodic nature of Spanish syllables). That is, perhaps the activation of phonology is so rapid in Spanish that it comes to dominate early processing and that phonological information from vowels makes vowel TL primes ineffective at activating lexical candidates. In contrast, because English is a language in which the grapheme–phoneme correspondences for vowels are much more inconsistent than those in Spanish and, hence, presumably, more difficult to derive from a masked prime, one would not expect that the (the orthographically-based) masked priming effects in English would mimic the phonologically-based priming effects in Spanish. Although this type of account might have some promise, it would seem that creating an explanation for this Spanish–English difference based on the assumption that TL priming effects are entirely phonologically based in Spanish but not in English would appear to be somewhat of a challenge. The reason is that one would still need to explain exactly why it would be the case that the phonological codes for vowels would be irrelevant (or possibly inhibitory, see Perea & Acha, 2009) in the Spanish priming process.

Conclusion

The results in our Experiments 1, 2, and 3 indicate that vowel TL priming effects do exist in English, implying that Lupker et al.'s (2008) failure to obtain vowel TL priming was likely a Type II error. These results further imply that the orthographic code for English readers does not distinguish between consonant and vowel letters, a conclusion consistent with the assumptions of most current orthographic coding models i.e., both the "noisy position" models (Adelman, 2011; Davis, 2010; Gómez et al., 2008; Norris & Kinoshita, 2012; Norris et al., 2010) and the "local-context" or "open-bigram" models (Grainger et al., 2006; Grainger & Van Heuven, 2003; Schoonbaert & Grainger, 2004; Whitney, 2001; Whitney & Marton, 2013). Therefore, although there clearly are C-V processing differences in reading, those differences appear to arise at a stage later than orthographic coding, likely a stage that involves phonological processing. Further research will be necessary in order to characterize the precise nature of the processing that is responsible for producing those differences and in what languages such differences arise.

Résumé

La plupart des modèles de codage orthographique s'appuient sur l'hypothèse voulant que le code orthographique ne fait pas de distinction entre voyelles et consonnes, si bien que ces modèles ne prédisent aucune différence entre les effets d'une inversion de voyelles (cisano-CASINO) et d'une inversion de consonnes (caniso-CASINO). Or, les données disponibles fournissent des preuves attestant d'une distinction entre les voyelles et les consonnes au niveau du code orthographique. Essentiellement, il a été démontré, au moyen de tâches de décision lexicale par amorçage masqué principalement effectuées en espagnol, qu'il existait uneffet d'amorçage dû aux amorces d'inversion de consonnes (p. ex, caniso), mais pas lorsqu'il y avait inversion de voyelles (p. ex. cisano). Les présentes expériences visaient à étudier ce schéma. L'expérience 1, fondée sur le stimulus de Schubert, Kinoshita et Norris' (2018), qui ne démontrait aucune différence entre les consonnes et les voyelles lors d'une tâche sans amorce avec mots identiques et différents, ne démontrait aucune différence entre les consonnes et les voyelles dans les effets d'amorçage masqué par inversion de lettres sur la décision lexicale indiquant, pour la première fois, un effet d'amorçage par inversion de voyelles lors de cette tâche. L'expérience 2, qui utilisait le stimulus de l'expérience 1a de Lupker, Perea et Davis, démontrait également un effet d'amorçage faible mais non négligeable du fait de l'inversion de voyelles (une non-répétition de cette expérience), et démontrait encore une fois l'effet d'amorçage dû à l'inversion de consonnes signalé à l'origine par ces auteurs. Lors de l'expérience 3, l'amorçage par inversion de lettres n'était pas, pour l'essentiel, touché par la nature des lettres inversées (voyelle ou consonne) ou par la fréquence de la cible, une variable qui distinguait les stimuli des expériences 1 et 2. Ces résultats, qui sont étayés par les potentiels évoqués observés par d'autres laboratoires, donnent à penser que les différences entre les inversions de consonnes et de voyelles, lorsqu'elles surviennent en anglais, ne sont probablement pas dues à la nature du code orthographique.

Mots-clés : amorçage par inversion de lettres, consonnes et voyelles, amorçage masqué, décision lexicale.

References

Adelman, J. S. (2011). Letters in time and retinotopic space. *Psychological Review, 118,* 570–582. http://dx.doi.org/10.1037/a0024811

Baayen, R. H. (2008). *Analyzing linguistic data: A practical introduction to statistics using R. Processing*. Cambridge, UK: Cambridge University Press. Retrieved from http://www.sfs.uni-tuebingen.de/~hbaayen/publications/baayenCUPstats.pdf. http://dx.doi.org/10.1017/CBO9780511801686

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59,* 390–412. http://dx.doi.org/10.1016/j.jml.2007.12.005

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., . . . Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods, 39,* 445–459. http://dx.doi.org/10.3758/BF03193014

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67,* 1–48. http://dx.doi.org/10.18637/jss.v067.i01

Berent, I. (1997). Phonological priming in the lexical decision task: Regularity effects are not necessary evidence for assembly. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1727–1742. http://dx.doi.org/10.1037/0096-1523.23.6.1727

Berent, I., & Perfetti, C. A. (1995). A rose is a REEZ: The two-cycles model of phonology assembly in reading english. *Psychological Review, 102,* 146–184. http://dx.doi.org/10.1037/0033-295X.102.1.146

Brown, P., & Besner, D. (1987). The assembly of phonology in oral reading: A new model. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 471–489). Hillsdale, NJ: Erlbaum.

Caramazza, A., & Hillis, A. E. (1990). Spatial representation of words in the brain implied by studies of a unilateral neglect patient. *Nature, 346,* 267–269. http://dx.doi.org/10.1038/346267a0

Carr, T. H., & Pollatsek, A. (1985). Recognizing printed words: A look at current models. *Reading Research: Advances in Theory and Practice, 5,* 1–82.

Carreiras, M., Gillon-Dowens, M., Vergara, M., & Perea, M. (2009). Are vowels and consonants processed differently? Event-related potential evidence with a delayed letter paradigm. *Journal of Cognitive Neuroscience, 21,* 275–288. http://dx.doi.org/10.1162/jocn.2008.21023

Carreiras, M., & Price, C. J. (2008). Brain activation for consonants and vowels. *Cerebral Cortex, 18,* 1727–1735. http://dx.doi.org/10.1093/cercor/bhm202

Carreiras, M., Vergara, M., & Perea, M. (2007). ERP correlates of transposed-letter similarity effects: Are consonants processed differently from vowels? *Neuroscience Letters, 419,* 219–224. http://dx.doi.org/10.1016/j.neulet.2007.04.053

Carreiras, M., Vergara, M., & Perea, M. (2009). ERP correlates of transposed-letter priming effects: The role of vowels versus consonants. *Psychophysiology, 46,* 34–42. http://dx.doi.org/10.1111/j.1469-8986.2008.00725.x

Chetail, F., & Content, A. (2012). The internal structure of chaos: Letter category determines visual word perceptual units. *Journal of Memory and Language, 67,* 371–388. http://dx.doi.org/10.1016/j.jml.2012.07.004

Chetail, F., Drabs, V., & Content, A. (2014). The role of consonant/vowel organization in perceptual discrimination. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40,* 938–961. http://dx.doi.org/10.1037/a0036166

Chetail, F., Ranzini, M., De Tiège, X., Wens, V., & Content, A. (2018). The consonant/vowel pattern determines the structure of orthographic representations in the left fusiform gyrus. *Cortex, 101,* 73–86. http://dx.doi.org/10.1016/j.cortex.2018.01.006

Colombo, L., Spinelli, G., & Lupker, S. J. (2019). The impact of consonant-vowel transpositions on masked priming effects in Italian and English. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*. Advance online publication. http://dx.doi.org/10.1177/1747021819867638

Coltheart, M., Davelaar, E., Jonasson, J. F., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance VI* (pp. 535–555). Hillsdale, NJ: Erlbaum.

Comesaña, M., Soares, A. P., Marcet, A., & Perea, M. (2016). On the nature of consonant/vowel differences in letter position coding: Evidence from developing and adult readers. *British Journal of Psychology, 107,* 651–674. http://dx.doi.org/10.1111/bjop.12179

Davis, C. J. (2010). The spatial coding model of visual word identification. *Psychological Review, 117,* 713–758. http://dx.doi.org/10.1037/a0019738

Davis, C. J., & Lupker, S. J. (2006). Masked inhibitory priming in english: Evidence for lexical inhibition. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 668–687. http://dx.doi.org/10.1037/0096-1523.32.3.668

Davis, C. J., & Lupker, S. J. (2017). A backwards glance at words: Using reversed-interior masked primes to test models of visual word identification. *PLoS ONE, 12*(12), e0189056. http://dx.doi.org/10.1371/journal.pone.0189056

Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology, 5,* 781. http://dx.doi.org/10.3389/fpsyg.2014.00781

Duñabeitia, J. A., & Carreiras, M. (2011). The relative position priming effect depends on whether letters are vowels or consonants. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 1143–1163. http://dx.doi.org/10.1037/a0023577

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 680–698. http://dx.doi.org/10.1037/0278-7393.10.4.680

Forster, K. I., Davis, C., Schoknecht, C., & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *The Quarterly Journal of Experimental Psychology, 39,* 211–251. http://dx.doi.org/10.1080/14640748708401785

Frankish, C., & Barnes, L. (2008). Lexical and sublexical processes in the perception of transposed-letter anagrams. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 61,* 381–391. http://dx.doi.org/10.1080/17470210701664880

Frankish, C., & Turner, E. (2007). SIHGT and SUNOD: The role of orthography and phonology in the perception of transposed letter anagrams. *Journal of Memory and Language, 56,* 189–211. http://dx.doi.org/10.1016/j.jml.2006.11.002

Gibbs, P., & Van Orden, G. C. (1998). Pathway selection's utility for control of word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1162–1187. http://dx.doi.org/10.1037/0096-1523.24.4.1162

Gómez, P., Ratcliff, R., & Perea, M. (2008). The overlap model: A model of letter position coding. *Psychological Review, 115,* 577–600. http://dx.doi.org/10.1037/a0012667

Grainger, J. (2018). Orthographic processing: A ‘mid-level’ vision of reading: The 44th Sir Frederic Bartlett Lecture. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 71,* 335–359. http://dx.doi.org/10.1080/17470218.2017.1314515

Grainger, J., & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language, 35,* 623–647. http://dx.doi.org/10.1006/jmla.1996.0033

Grainger, J., Granier, J. P., Farioli, F., Van Assche, E., & van Heuven, W. J. B. (2006). Letter position information and printed word perception: The relative-position priming constraint. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 865–884. http://dx.doi.org/10.1037/0096-1523.32.4.865

Grainger, J., & Van Heuven, W. J. B. (2003). Modeling letter position coding in printed word perception. In P. Bonin (Ed.), *Mental lexicon: “Some words to talk about words”* (pp. 1–23). Hauppauge, NY: Nova Science Publishers.

Guerrera, C., & Forster, K. (2008). Masked form priming with extreme transposition. *Language and Cognitive Processes, 23,* 117–142. http://dx.doi.org/10.1080/01690960701579722

Johnson, R. L. (2007). The flexibility of letter coding: Nonadjacent letter transposition effects in the parafovea. In W. R. van Gompel, M. Fisher & & R. L. H. Murray (Eds.), *Eye movements: A window on mind and brain* (pp. 425–440). Oxford, UK: Elsevier. http://dx.doi.org/10.1016/B978-008044980-7/50021-5

Kessler, B., & Treiman, R. (2001). Relationship between sounds and letters in English monosyllables. *Journal of Memory and Language, 44,* 592–617. http://dx.doi.org/10.1037/e501882009-555

Kinoshita, S., & Norris, D. (2009). Transposed-letter priming of prelexical orthographic representations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 1–18. http://dx.doi.org/10.1037/a0014277

Kinoshita, S., & Norris, D. (2010). Masked priming effect reflects evidence accumulated by the prime. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 63,* 194–204. http://dx.doi.org/10.1080/17470210902957174

Lenth, R. V. (2018). emmeans: Estimated marginal means, aka least-squares means. (R package Version 1.1) [Computer software]. Retrieved from https://cran.r-project.org/web/packages/emmeans/emmeans.pdf

Levy, R. (2014). Using R formulae to test for main effects in the presence of higher-order interactions. *ArXiv Preprint ArXiv*. Advance online publication. Retrieved from https://arxiv.org/pdf/1405.2094.pdf

Lo, S., & Andrews, S. (2015). To transform or not to transform: Using generalized linear mixed models to analyse reaction time data. *Frontiers in Psychology, 6,* 1171. http://dx.doi.org/10.3389/fpsyg.2015.01171

Lupker, S. J., & Davis, C. J. (2009). Sandwich priming: A method for overcoming the limitations of masked priming by reducing lexical competitor effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 618–639. http://dx.doi.org/10.1037/a0015278

Lupker, S. J., Nakayama, M., & Perea, M. (2015). Is there phonologically based priming in the same-different task? Evidence from Japanese-English bilinguals. *Journal of Experimental Psychology: Human Perception and Performance, 41,* 1281–1299. http://dx.doi.org/10.1037/xhp0000087

Lupker, S. J., Nakayama, M., & Yoshihara, M. (2018). Phonologically-based priming in the same-different task with L1 readers, *44,* 1317–1324. http://dx.doi.org/10.1037/xlm0000515

Lupker, S. J., Perea, M., & Davis, C. J. (2008). Transposed-letter effects: Consonants, vowels and letter frequency. *Language and Cognitive Processes, 23,* 93–116. http://dx.doi.org/10.1080/01690960701579714

Lupker, S. J., Zhang, Y. J., Perry, J. R., & Davis, C. J. (2015). Superset versus substitution-letter priming: An evaluation of open-bigram models. *Journal of Experimental Psychology: Human Perception and Performance, 41,* 138–151. http://dx.doi.org/10.1037/a0038392

Morey, R. D., Rouder, J. N., & Jamil, T. (2015). Bayes factor: Computation of Bayes factors for common designs. R Package Version 0.9. Retrieved from http://cran.fhcrc.org/web/packages/BayesFactor/BayesFactor.pdf

New, B., Araújo, V., & Nazzi, T. (2008). Differential processing of consonants and vowels in lexical access through reading. *Psychological Science, 19,* 1223–1227. http://dx.doi.org/10.1111/j.1467-9280.2008.02228.x

New, B., & Nazzi, T. (2014). The time course of consonant and vowel processing during word recognition. *Language, Cognition and Neuroscience, 29,* 147–157. http://dx.doi.org/10.1080/01690965.2012.735678

Norris, D., & Kinoshita, S. (2008). Perception as evidence accumulation and Bayesian inference: Insights from masked priming. *Journal of Experimental Psychology: General, 137,* 434–455. http://dx.doi.org/10.1037/a0012799

Norris, D., & Kinoshita, S. (2012). Reading through a noisy channel: Why there’s nothing special about the perception of orthography. *Psychological Review, 119,* 517–545. http://dx.doi.org/10.1037/a0028450

Norris, D., Kinoshita, S., & van Casteren, M. (2010). A stimulus sampling theory of letter identity and order. *Journal of Memory and Language, 62,* 254–271. http://dx.doi.org/10.1016/j.jml.2009.11.002

Parkin, A. J., & Ellingham, R. (1983). Phonological recoding in lexical decision: The influence of pseudohomophones. *Language and Speech, 26,* 81–90. http://dx.doi.org/10.1177/002383098302600105

Perea, M., & Acha, J. (2009). Does letter position coding depend on consonant/vowel status? Evidence with the masked priming technique. *Acta Psychologica, 130,* 127–137. http://dx.doi.org/10.1016/j.actpsy.2008.11.001

Perea, M., & Lupker, S. J. (2003a). Does jugde activate COURT? Transposed-letter similarity effects in masked associative priming. *Memory & Cognition, 31,* 829–841. http://dx.doi.org/10.3758/BF03196438

Perea, M., & Lupker, S. J. (2003b). Transposed-letter confusability effects in masked form priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming: The state of the art* (pp. 97–120). Philadelphia, PA: Psychology Press.

Perea, M., & Lupker, S. J. (2004). Can CANISO activate CASINO? Transposed-letter similarity effects with nonadjacent letter positions. *Journal of Memory and Language, 51,* 231–246. http://dx.doi.org/10.1016/j.jml.2004.05.005

Pexman, P. M., Lupker, S. J., & Jared, D. (2001). Homophone effects in lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 139–156. http://dx.doi.org/10.1037/0278-7393.27.1.139

Pexman, P. M., Lupker, S. J., & Reggin, L. D. (2002). Phonological effects in visual word recognition: Investigating the impact of feedback activation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28,* 572–584. http://dx.doi.org/10.1037/0278-7393.28.3.572

R Core Team. (2015). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://cran.r-project.org/doc/manuals/r-release/R-ints.html

Rubenstein, H., Lewis, S. S., & Rubenstein, M. A. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Memory and Language, 10,* 645–657. http://dx.doi.org/10.1016/S0022-5371(71)80071-3

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime: User’s guide*. Pittsburgh, PA: Psychology Software Tools.

Schoonbaert, S., & Grainger, J. (2004). Letter position coding in printed word perception: Effects of repeated and transposed letters. *Language and Cognitive Processes, 19,* 333–367. http://dx.doi.org/10.1080/01690960344000198

Schubert, T., Kinoshita, S., & Norris, D. (2018). What causes the greater perceived similarity of consonant-transposed nonwords? *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 71,* 642–656.

Segui, J., & Grainger, J. (1990). Priming word recognition with orthographic neighbors: Effects of relative prime-target frequency. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 65–76. http://dx.doi.org/10.1037/0096-1523.16.1.65

Singmann, H., & Kellen, D. (2017). An introduction to mixed models for experimental psychology. In D. Spieler & E. Schumacher (Eds.), *New methods in neuroscience and cognitive psychology* (pp. 1–39). Hove, UK: Psychology Press. Retrieved from https://cran.r-project.org/web/packages/afex/vignettes/introduction-mixed-models.pdf

Stone, G. O., & Van Orden, G. C. (1993). Strategic control of processing in word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 744–774. http://dx.doi.org/10.1037/0096-1523.19.4.744

Van Assche, E., & Grainger, J. (2006). A study of relative-position priming with superset primes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 399–415. http://dx.doi.org/10.1037/0278-7393.32.2.399

Vergara-Martínez, M., Perea, M., Marín, A., & Carreiras, M. (2011). The processing of consonants and vowels during letter identity and letter position assignment in visual-word recognition: An ERP study. *Brain and Language, 118,* 105–117. http://dx.doi.org/10.1016/j.bandl.2010.09.006

Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin & Review, 8,* 221–243. http://dx.doi.org/10.3758/BF03196158

Whitney, C., Bertrand, D., & Grainger, J. (2011). On coding the position of letters in words: A test of two models. *Experimental Psychology, 59,* 109–114. http://dx.doi.org/10.1027/1618-3169/a000132

Whitney, C., & Marton, Y. (2013). *The SERIOL2 model of orthographic processing*. Retrieved from http://eric.ed.gov/?id=ED543279

Winskel, H., & Perea, M. (2013). Consonant/vowel asymmetries in letter position coding during normal reading: Evidence from parafoveal previews in Thai. *Journal of Cognitive Psychology, 25,* 119–130. http://dx.doi.org/10.1080/20445911.2012.753077

Appendix A

List of Stimuli Used in Experiment 1

Base word	CCTL	CCSL	VVTL	VVSL
SPECULATE	specutale	specurane	specalute	specolite
PROXIMATE	promixate	provinate	proxamite	proxumote
RESIDENCE	redisence	retirence	resedince	resudance
POSTULATE	postutale	postudane	postalute	postilote
METABOLIC	mebatolic	megasolic	metobalic	metibulic
MACHINERY	machireny	machisedy	macheniry	machonury
RESONANCE	renosance	retolance	resanonce	resunince
VIGILANCE	viligance	vipinance	vigalince	vigolunce
GLYCERINE	glyrecine	glyfenine	glycirene	glycarone
CINEMATIC	cinetamic	cinesafic	cinametic	cinomutic
MANDATORY	mandaroty	madasony	mandotary	maditury
DEVELOPER	delevoper	desegoper	devoleper	devilaper
INDELIBLE	inledible	inrenible	indileble	indalible
ALLIGATOR	allitagor	allisador	alligotar	alligutir
PARASITIC	pasaritic	palanitic	parisatic	parosetic
EXONERATE	exorenate	exolesate	exonarete	exonirute
PRIVILEGE	prilivege	prinibege	privelige	privoluge
AMPLITUDE	amplidute	amplisune	amplutide	amplotade
VENERABLE	verenable	vesedable	venareble	veniruble
HABITABLE	hatibable	hasivable	habatible	habotuble
ELABORATE	elarobate	elasovate	elabarote	elabirute
PARAMETER	paratemer	paraseker	paremater	paromiter
ATTRIBUTE	attritube	attrisuve	attrubite	attrebote
PROMENADE	pronemade	prodewade	promanede	prominode
FORTUNATE	fortutane	fortusale	fortanute	fortinote
TERMINATE	termitane	termisade	termanite	termonute
ULTIMATUM	ultitamum	ultisafum	ultimutam	ultimitom
ERADICATE	eracidate	eramilate	eridacate	erodacate
FANATICAL	fanacital	fanamisal	fanatacil	fanatucol
PRESIDENT	predisent	prenitent	presedint	presadont
MAGNITUDE	magnidute	magnirune	magnutide	magnitade
EVOLUTION	evotulion	evosunion	evulotion	evalition
CUSTOMARY	custoramy	custolafy	custamory	custimury
VEGETABLE	vetegable	vesepable	vegateble	vegotible

(*Appendices continue*)

Appendix A (*continued*)

Base word	CCTL	CCSL	VVTL	VVSL
CONJUGATE	conjutage	conjuvane	conjagute	conjigote
INCIDENCE	indicence	inpifence	incedince	incudance
SOLICITOR	socilitor	soniritor	solocitor	solacetor
TERRITORY	terriroty	terrisony	terrotiry	terratury
CHOCOLATE	cholocate	chosorate	chocalote	choculite
INSOLENCE	inlosence	inrodence	insulonce	inselance
ITINERARY	itirenary	itiresaty	itinarery	itinurory
DEODORANT	deorodant	deosotant	deodaront	deodirunt
ACADEMICS	acamedics	acasetics	acadimecs	acadomucs
GERMINATE	germitane	germisare	germanite	germonute
ELIMINATE	elinimate	elirikate	elimanite	elimunote
FORMULATE	formutale	formusare	formalute	formilote
AUTHORIZE	authozire	authonive	authiroze	autharaze
VERSATILE	versalite	versanire	versitale	versotule
CANDIDATE	canditade	candisane	candadite	candodute
HURRICANE	hurrinace	hurritade	hurracine	hurrucone
ORIGINATE	orinigate	orisivate	origanite	origonute
CULTIVATE	cultitave	cultigare	cultavite	cultovute
CIRCULATE	circutale	circusane	circalute	circolite
PROSECUTE	procesute	proferute	prosucete	prosacote
TOLERABLE	torelable	tonesable	tolareble	toliroble
NAVIGATOR	navitagor	nabirator	navagitor	navogutor
CULMINATE	culmitane	culmisade	culmanite	culmonute
APPARATUS	appatarus	appanalus	apparutas	apparitos
INTRICATE	intritace	intrinase	intracite	intrucote
REPUTABLE	retupable	resuvable	repatuble	repoteble
DISCOVERY	disvocery	disbofery	discevory	discavury
PLANETARY	platenary	plaselary	planatery	planotiry
PREJUDICE	predujice	prenuvice	prejiduce	prejadoce
SIGNATURE	signarute	signalude	signutare	signotire
MODERATOR	modetorar	modesanar	modaretor	modiruter
STIPULATE	stilupate	stiruvate	stipalute	stipolite
EVOCATIVE	evotacive	evosanive	evocitave	evocutive
PROMINENT	proniment	prorilent	promenint	promanunt
OXIDATION	oxitadion	oxisanion	oxiditaion	oxidutaon
MASCULINE	mascunile	mascurise	mascilune	mascolane
DECORATOR	decotarar	decosanar	decaroter	decuriter
CORRELATE	corretale	correnase	corralete	corrilute
MIGRATORY	migraroty	migrasony	migrotary	migritury
RATIONALE	ratiolane	ratiotade	ratianole	ratiunile
EXUBERANT	exurebant	exusevant	exeburant	exiborant
HEXAGONAL	hexanogal	hexasopal	hexaganol	hexagunel
MISERABLE	miresable	miletable	misareble	misorible
ACROBATIC	acrotabic	acrogasic	acrobitac	acrobetoc
ENDURABLE	enrudable	ensunable	endaruble	endorible
STATUTORY	staturoty	statusony	statotury	statitary

Note. MANDATORY, SOLICITOR, INSOLENCE, OXIDATION, NAVIGATOR, MODERATOR and DECORATOR were primed by primes that involved what appears to be a typographical error. Those seven targets were not included in the analyses.

(*Appendices continue*)

Appendix B

List of Stimuli Used in Experiment 2

Base word	CCTL	CCSL	VVTL	VVSL
ACADEMY	adacemy	abanemy	acedamy	acidomy
ADVISORY	adsivory	adnicory	advosiry	advasery
AMATEUR	atameur	afaneur	ametaur	amutiur
ANIMAL	aminal	asiral	anamil	anemol
BELOVED	bevoled	bewoted	belevod	belavid
BENEFIT	befenit	betemit	benifet	benafot
BESIDE	bedise	bebine	bisede	basude
CAFETERIA	cateferia	caleberia	cefateria	cifuteria
CAMERA	carema	casena	cemara	cimura
CAPACITY	cacapity	casagity	capicaty	capecoty
CAPITAL	catipal	cafigal	capatil	capotel
CARDINAL	carnidal	carminal	cirdanal	cerdenal
CATEGORY	cagetory	capefory	catogery	catagury
CEREMONY	cemerony	cenesony	ceromeny	ceramuny
CLINICAL	clicinal	clisimal	clinacil	clinucel
COMEDY	codemy	cobeny	cemody	cimudy
CONSIDER	condiser	conbicer	cinsoder	censader
COVERAGE	corevage	cocewage	covarege	covurige
CRIMINAL	crinimal	crisival	crimanil	crimonel
DEBATE	detabe	delahe	dabete	dobute
DECADE	dedace	debave	dacede	dicude
DELICATE	decilate	desifate	delacite	delocete
DENSITY	dentisy	denficy	dinsety	donsuty
DISPUTE	distupe	disluge	duspite	daspote
DOMINANT	donimant	docirant	domanint	domenunt
EDITOR	etidor	efibor	edotir	edatur
ELABORATE	elarobate	elacodate	elobarate	eluberate
EVIDENT	edivent	ebiwent	evedint	evadunt
FORTUNE	fornute	formuke	furtone	fertane
GRATEFUL	grafetul	gralekul	gretaful	grotiful
HERITAGE	hetirage	helicage	heratige	herotuge
INDICATE	incidate	insibate	indacite	inducete
LIBERAL	lirebal	linedal	libarel	liborul
LITERAL	liretal	linefal	litarel	litorul
LOCATE	lotace	lofase	lacote	lucete
LOGICAL	locigal	losipal	logacil	logecul
MARGINAL	marnigal	marmipal	mirganal	mergonal
MARINE	manire	macise	mirane	morene
MEDICINE	mecidine	mesibine	midecine	maducine
MEMORY	meromy	menowy	momery	mumary
MILITARY	mitilary	mifikary	milatiry	milutery
MISTAKE	miskate	mishafe	mastike	mosteke
MOBILE	molibe	motide	mibole	mebale
MODERATE	moredate	monebate	modarete	modurite
NUMERICAL	nuremical	nunewical	numirecal	numurocal
OPERATOR	orepator	onegator	oparetor	opuritor
OPTIMAL	opmital	opcifal	optamil	optomel
ORIGINAL	orinigal	orimipal	origanil	origonel
PACIFIC	paficic	patisic	picafic	pecofic
PARENT	panert	pamest	perant	porint
POLICY	pocily	posity	pilocy	pelacy
POPULAR	polupar	potugar	popalur	popelir
PROPOSAL	prosopal	procogal	propasol	propusel
PROVIDE	prodive	probice	privode	prevude
QUALIFY	quafily	quakity	quilafy	quelofy
QUALITY	quatily	quafidy	quilaty	quolety

(*Appendices continue*)

Appendix B (*continued*)

Base word	CCTL	CCSL	VVTL	VVSL
RADICAL	racidal	rasibal	radacil	radocel
RAPIDLY	radiply	rabigly	ripadly	repodly
REFUSAL	resufal	renutal	refasul	refosil
REGULAR	relugar	retupar	regalur	regolir
RELATIVE	retalive	refakive	relitave	reletove
RELIGION	regilion	repifion	rilegion	ralugion
REMOTE	retome	relone	romete	ramute
REMOVAL	revomal	reconal	remavol	remuvel
RESIDENT	redisent	rebicent	resedint	resadunt
RESUME	remuse	revune	ruseme	rasime
RETIRE	rerite	recile	ritere	ratore
ROMANTIC	ronamtic	rovastic	ramontic	remuntic
SALINE	sanile	samite	silane	selone
SENATOR	setanor	selamor	senotar	senutir
SENTIMENT	senmitent	senvilent	sintement	sontament
SPECIFIC	speficic	spetisic	spicefic	spocafic
SPECIMEN	spemicen	speniven	specemin	specuman
STOLEN	sloten	skofen	stelon	stalun
STORAGE	stogare	stopave	staroge	sturege
STRATEGY	stragety	strapely	stretagy	strotigy
TRIBUTE	tritube	trilude	trubite	trabete
VALIDITY	vadility	vabifity	viladity	voledity
VELOCITY	vecolity	vesofity	velicoty	velecaty
VETERAN	veretan	vecelan	vetaren	veturin

Note. Incibate was used as the CCTL prime instead of incidate in Experiment 2 for the word target INDICATE. That target was removed from the analyses in Experiment 2.

Appendix C

List of Stimuli Used in Experiment 3

Base word	CCTL	CCSL	VVTL	VVSL
High frequency base word				
PREPARE	pperare	phetare	prapere	pripore
SATURDAY	sarutday	sacugday	satarduy	satordiy
SOMEDAY	sodemay	sonehay	somadey	somiduy
RECOGNIZE	regocnize	rewornize	recignoze	recegnaze
CONTINUE	connitue	conripue	contunie	contanee
NOTICE	nocite	nodire	nitoce	nutace
SOMEHOW	sohemow	socerow	somohew	somuhaw
COLLEGE	colgele	colpere	celloge	callige
SENATOR	setanor	selamor	senotar	senutir
AWESOME	awemose	aweloge	awoseme	awisame
POWERFUL	porewful	pocesful	powurfel	powarfil
PRIVATE	pritave	prisame	pravite	prevote
MESSAGE	mesgase	meshane	massege	mossige
FOREVER	foverer	fogeker	ferover	fariver
CAREFUL	caferul	casedul	carufel	carofil
FAMILY	falimy	fanipy	fimaly	fumely
NOWHERE	nowrehe	nowsege	newhore	nawhire
EVIDENCE	edivence	emitence	evedince	evodance
PROMISE	prosime	provite	primose	pramuse
HOSPITAL	hostipal	hosgival	hospatil	hospetul

(*Appendices continue*)

Appendix C (*continued*)

Base word	CCTL	CCSL	VVTL	VVSL
MANAGER	maganer	mawaver	manegar	manigor
SECRETARY	secterary	secpesary	secratery	secrotiry
HONEST	hosent	horett	henost	hinast
GENERAL	gerenal	gelefal	genarel	genoril
FUNERAL	furenal	fujeval	funarel	funoril
OPERATION	orepation	omegation	oparetion	opirution
MISTAKE	miskate	mishafe	mastike	mosteke
PRISON	psiron	pdinon	prosin	presun
FIGURE	firuge	fimule	fugire	fagore
SECOND	senocd	sezord	socend	sacind
INNOCENT	inconent	inmosent	innecont	innucint
MEMORY	meromy	menowy	momery	mumary
POSITIVE	potisive	pojicive	pisotive	pasutive
POLICE	pocile	pofise	piloce	pulace
DIFFERENT	difrefent	diflekent	deffirent	doffarent
HOWEVER	hovewer	honerer	hewover	hiwuver
SERVICE	sercive	serrite	sirvece	sarvoce
WELCOME	welmoce	welloge	wolceme	walcime
MINUTE	mitune	miduce	munite	monete
DIFFICULT	difcifult	difpitult	diffucilt	diffecalt
PRACTICE	praccite	pracside	prictace	pructoce
VILLAGE	vilgale	vilrafe	vallige	vulloge
SECURITY	serucity	sevufity	seciruty	secoraty
ROMANTIC	ronamtic	rovastic	romintac	romuntec
NECESSARY	nesecsary	nezensary	necassery	necissury
COMPUTER	comtuper	comfuser	competur	compatir
TERRIFIC	terfiric	terpisic	tirrefic	tarrofic
REGULAR	relugar	retupar	regalur	regolir
APOLOGIZE	apogolize	apocomize	apoligoze	apolugeze
MEDICAL	mecidal	menigal	medacil	meducol
MAGAZINE	mazagine	macajine	magizane	magezone
ANIMAL	aminal	asiral	anamil	anemol
DECIDE	dedice	deline	dicede	dacude
FAMILIAR	falimiar	faviriar	fimaliar	femuliar
CONSIDER	condiser	conbicer	consedir	consadur
WHATEVER	wtahever	wradever	whetaver	whotiver
IMAGINE	igamine	ivanine	imigane	imogene
CRIMINAL	crinimal	crisival	crimanil	crimonel
MEDICINE	mecidine	mesibine	midecine	maducine
CAMERA	carema	casena	cemara	cimura
EVENING	eneving	efeding	evineng	evonang
PURPOSE	pursope	purtore	porpuse	pirpase
PERSONAL	pernosal	pervocal	persanol	persinul
MILITARY	mitilary	mifikary	milatiry	milutery
MACHINE	macnihe	macpite	michane	mochune
COLONEL	conolel	corofel	colenol	colanil
FORGIVE	forvige	forfire	firgove	farguve
TOGETHER	totegher	tojefher	tegother	tagither
NATURAL	narutal	nanukal	natarul	naterol
PICTURE	picrute	pichuje	puctire	pectare
FAVORITE	farovite	facodite	favirote	faverute
PRESIDENT	predisent	prenitent	presedint	presadont
SUPPOSE	supsope	supvoce	soppuse	sippase
DETECTIVE	decettive	demestive	deticteve	detactove
PLANET	pnalet	pvadet	plenat	plonit
POSITION	potision	pocidion	pisotion	pasetion
TELEPHONE	tepelhone	teterhone	telophene	telaphune
DIRECTOR	dicertor	diteztor	dirocter	diractur
SEVERAL	sereval	sesetal	sevarel	sevirol

(*Appendices continue*)

Appendix C (*continued*)

Base word	CCTL	CCSL	VVTL	VVSL
PRESSURE	presruse	preshute	prussere	prassore
Low frequency base word				
APPARENT	aprapent	apnabent	apperant	apporunt
MODERATE	moredate	monebate	modarete	modurite
MIGRATORY	migraroty	migrasony	migrotary	migritury
COHERENT	corehent	colefent	cehorent	cuharent
NUMERICAL	nuremical	nunewical	numirecal	numurocal
DENSITY	dentisy	denficy	dinsety	donsuty
VELOCITY	vecolity	vesofity	velicoty	velecaty
MATINEE	manitee	mahisee	mitanee	mutonee
ADVOCACY	adcovacy	adsowacy	advacocy	advecucy
MINERAL	mirenal	mivetal	meniral	munoral
BINARY	birany	bimaly	baniry	bonery
OBSOLETE	oblosete	obnocete	obselote	obsalute
OPPONENT	opnopent	opsoment	oppenont	oppanint
DECADE	dedace	debave	dacede	dicude
CALAMITY	camality	canakity	calimaty	calomety
PARASITE	pasarite	pacafite	parisate	parosute
ABDOMEN	abmoden	abwoten	abdemon	abdumin
FUSELAGE	fulesage	furecage	fesulage	fosilage
IMPERIAL	imrepial	imleqial	impireal	impuroal
QUALIFY	quafily	quakity	quilafy	quelofy
HABITAT	hatibat	hasidat	habatit	habetot
INSULIN	inlusin	inhucin	insilun	insalen
LATERAL	laretal	lavedal	latarel	latoril
OBLIVION	obvilion	obrihion	obloviin	oblavien
ASTEROID	asretoid	asvedoid	astoreid	asturaid
RACIST	rasict	ranilt	ricast	recust
CONSUME	conmuse	conwuce	cunsome	cansime
ACTIVATE	acvitate	acwidate	actavite	actuvote
RADICAL	racidal	rasibal	radacil	radocel
COMEDIAN	codemian	cokewian	cemodian	camudian
RAPIDLY	radiply	rabigly	ripadly	repodly
VALIDITY	vadility	vabifity	viladity	voledity
CATALOG	calatog	cakafog	catolag	catuleg
IMPUNITY	imnupity	imhubity	impinuty	impanoty
DISPUTE	distupe	disluge	duspite	daspote
ORGANIZE	ornagize	orlajize	orginaze	orgonuze
ENDURABLE	enrudable	ensunable	endaruble	endorible
EVIDENT	edivent	ebiwent	evedint	evadunt
RESONANCE	renosance	retolance	resanonce	resunince
MARITIME	matirime	madivime	miratime	morutime
ORGANISM	ornagism	ormajism	orginasm	orgunesm
RELOCATE	recolate	regofate	relacote	relucite
PEROXIDE	pexoride	pezoside	perixode	peruxade
ADVISORY	adsivory	adnicory	advosiry	advasery
HORIZON	hoziron	hocivon	horozin	horazen
REFUSAL	resufal	renutal	refasul	refosil
RESUME	remuse	revune	ruseme	rasime
PRIMATE	pmirate	pcinate	pramite	premote
RELATION	retalion	redarion	raletion	rolution
VIGILANCE	viligance	vipinance	vigalince	vigolunce
CARDINAL	carnidal	carminal	cirdanal	cerdenal
EXUBERANT	exurebant	exusevant	exeburant	exiborant
CATEGORY	cagetory	capefory	catogery	catagury
ARTISAN	arsitan	arcidan	artasin	arteson
APRICOT	apcirot	apsinot	aprocit	aprecut
CRITERIA	ctireria	cliceria	cretiria	cratoria
ESTIMATE	esmitate	esnidate	estamite	estumote

(*Appendices continue*)

Appendix C (*continued*)

Base word	CCTL	CCSL	VVTL	VVSL
SALINE	sanile	samite	silane	selone
DOMINANT	donimant	docirant	domanint	domenunt
OPTIMAL	opmital	opcifal	optamil	optomel
HERITAGE	hetirage	helicage	heratige	herotuge
NOVELIST	nolevist	norewist	novilest	novulast
METABOLIC	mebatolic	megasolic	metobalic	metibulic
RESTORE	resrote	resfole	rostere	ristare
REFUGEE	regufee	rejuhee	rufegee	rifagee
GLYCERINE	glyrecine	glyfenine	glycirene	glycarone
RATIONALE	ratiolane	ratiotade	ratianole	ratiunile
COMPILER	comliper	comvicer	compelir	compalor
MARGINAL	marnigal	marmipal	mirganal	mergonal
OPTIONAL	opniotal	opriomal	optaonil	opteonul
PARALLEL	palarlel	pavatlel	parellal	parillol
RESIDUE	redisue	reticue	risedue	rosadue
LITERAL	liretal	linefal	litarel	litorul
CLARINET	claniret	clamilet	cliranet	cluronet
BULLETIN	bultelin	bulsepin	bulliten	bullotun
ERADICATE	eracidate	eramilate	eridacate	erodacate
SATURN	sarutn	saducn	sutarn	sotern
ADVOCATE	adcovate	adsorate	advacote	advucite
GENERATE	genetare	genefale	genarete	genorite
SPATULA	spaluta	spahuda	sputala	spetila

Appendix D

R Code Used in the Analyses for Experiments 1, 2 and 3

The syntax of the R models used in Experiment 1: For the latency analysis, the model was: RT = glmer (RT ~ Letter Type × Transformation Type + (1|subject) + (1|item), family = γ(link = “identity”)). For the error rate analysis, a generalized linear mixed-effects model in lme4 was employed. The model was: Accuracy = glmer (accuracy ~ Letter Type × Transformation Type + (1|subject) + (1|item), family = “binomial”).

The syntax of the R models used in Experiment 2: For the latency analysis, the model was: RT = glmer (RT ~ Letter Type × Transformation Type + (1|subject) + (1|item), family = γ(link = “identity”)). For the error rate analysis, a generalized linear mixed-effects model in lme4 was employed. The model was: Accuracy = glmer (accuracy ~ Letter Type × Transformation Type + (1|subject) + (1|item), family = “binomial”).

The syntax of the R models used in Experiment 3: For the latency analysis, the model was: RT = glmer (RT ~ Letter Type × Transformation Type × Frequency + (1|subject) + (1|item), family = γ(link = “identity”), control = glmerControl (optimizer = “bobyqa”)). For the error rate analysis, a generalized linear mixed-effects model in lme4 was employed. The model was: Accuracy = glmer (accuracy ~ Letter Type × Transformation Type × Frequency + (1|subject) + (1|item), family = “binomial”).

Received June 20, 2019
Accepted September 22, 2019 ■