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On the Interaction of Letter Transpositions and Morphemic Boundaries

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Abstract

Investigations of the impact of morphemic boundaries on transposed-letter priming effects have yielded conflicting results. Five masked priming lexical decision experiments were conducted to examine the interaction of letter transpositions and morphemic boundaries with English suffixed derivations. Experiments 1-3 found that responses to monomorphemic target words (e.g., SPEAK) were facilitated to the same extent by morphologically related primes containing letter transpositions that did (SPEAEKR) or did not (SPEKAER) cross a morphemic boundary. This pattern was also observed in Experiments 4 and 5, in which the targets (e.g. SPEAKER) were the base forms of the transposed-letter primes. Thus, in these experiments the influence of the morphological structure of a transposed-letter prime did not depend on whether the letter transposition crossed a morphological boundary.

Readers rely on information about the morphological structure of the words that they read. Evidence that morphological constituents play a role in word recognition has been obtained in a variety of tasks and in a variety of languages. (For reviews of these findings, see Feldman, 1991; Henderson, 1985; Sandra, 1994; Seidenberg & Gonnerman, 2000.) Consequently, recent research has focused not on whether morphological structure influences word recognition, but instead on which aspects of morphological structure are relevant and how this structure is detected and used.

With regard to the latter question, one issue that has received much attention concerns the time course of morphological processing. One position is that morphological effects arise relatively early in the course of word recognition. For example, prelexical decomposition models (e.g., Rastle et al., 2004; Taft, 1979; Taft, 1994) posit that written words are parsed into their constituent morphemes and that representations of these morphemes serve as the ‘access units’ to the mental lexicon. Similarly, although connectionist models (Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999; Seidenberg & Gonnerman, 2000) eschew the prelexical/lexical distinction, these models also hold that morphological effects arise early in the course of processing. According to this account, morphological structure is captured in the “hidden” patterns of activation that represent visual word form— a level of representation that is comparable to the access units of pre-lexical decomposition models (see Rueckl & Aicher, 2008, for further discussion).

The alternative position is that morphological effects arise relatively late in processing— after lexical access has occurred. For example, in the supralexical model (Giraudo & Grainger, 2001; also see Diependaele, Sandra, & Grainger, 2009) morphemic representations are located between representations of whole-word form and higher-level semantic representations. Thus, on this view morphological decomposition occurs after

lexical access and reflects the role of morphological structure in accessing semantic information. Whole-word accounts (e.g., Feldman & Fowler, 1987; Lukatela, Gligorijevic, Kostic, & Turvey, 1980) also hold that morphological effects occur relatively late in the recognition process. These models deny that morphological decomposition ever takes place. Instead, each morphologically complex word is assumed to have its own representation, with these representations are organized such that morphological relationships affect processing (e.g., through an excitatory feedback process).

Although there may not be universal agreement on this point, in our view there is a convincing body of evidence indicating an early time course for morphological effects. This evidence takes many forms. One is masked morphological priming: the response to a target word is facilitated by the prior presentation of a morphologically related word (Feldman & Soltano, 1999; Rastle, Davis, & New, 2004). Given the brief duration of the primes (typically 30-60 ms) and the characteristic effects of various psycholinguistic manipulations, masked priming is generally taken to provide a window on the early processes at the 'front end' of word recognition (Forster, Davis, Schoknecht, & Carter, 1987; Grainger, 2008; Rastle et al., 2000). The early view is also supported by evidence of long-term morphological priming—the facilitation that results when many unrelated trials intervene between the presentation of a prime and its morphologically related target. For example, Rueckl and Galantucci (2005) demonstrated that long-term morphological priming has a modality-specific component with an early time course—further evidence that morphological structure influences the front end of reading.

Neurophysiological data provide converging support for this perspective. Neuroimaging studies have revealed that among the anatomical regions that are affected by both masked- and long-term morphological priming are sites within the occipitotemporal/fusiform region (Devlin et al., 2006; Gold & Rastle, 2007; Rueckl et al., 2005)—a region which is thought to underlie modality-specific orthographic processing. In a different vein, studies of evoked response potentials (ERPs) have revealed that morphological manipulations affect the early N250 component (Morris et al., 2007), again suggesting that morphological effects arise early in the course of visual word recognition.

Thus, a broad variety of evidence supports the conclusion that morphological structure has an early influence on visual word recognition. One question that follows from this conclusion concerns the nature of the process that extracts this structure from the visual input. Several possibilities have been proposed. For example, in the affix-stripping model (Taft, 1979; Taft & Forster, 1975), the reader is assumed to strip the affixes from a word using an active, left-to-right search, with the remainder of word used to access the mental lexicon. Alternatively, morphological decomposition could be accomplished within an interactive-activation framework in a network with morpheme detectors situated between letter and word detectors (Taft, 1994). Distributed connectionist accounts (Plaut & Gonnerman, 2000) suggest a third possibility—that visual inputs are mapped onto distributed patterns of activation that are organized by morphological regularities in the mapping between the visual and semantic properties of written words.

It is fair to say that each of these alternatives is underspecified and in need of further development. Until recently, the empirical results needed to drive theory development have been lacking (the exception being some early research testing the predictions of the affix-stripping model, e.g. Rubin, Becker, & Freeman, 1979; Taft & Forster, 1975). However, in recent years research has begun to explore several possible constraints on models of early morphological processing. First, readers must cope with pseudomorphological structure (i.e., words such as CORNER, which appear to be componential with regard to form, but are clearly not componential at the level of meaning). A significant body of research has

investigated the effects of pseudomorphological structure under various circumstances (Rastle et al., 2004; Devlin, 2004; Diependaele et al., 2005; Feldman et al., 2004; Feldman, O'Connor, & Moscoso del Prado Martín, 2009; Morris et al., 2007; Gold & Rastle, 2007; Marslen-Wilson et al. 2008). A second constraint is the quasiregularity of orthographic forms. In English, for example, nearly 40% of the derived words are written such their full form is not simply the concatenation of the intact forms of their constituent morphemes (Baayen et al., 1993; cited by McCormick et al., 2008). (These discrepancies arise from mechanisms such as letter doubling (e.g., slipper, not sliper), letter deletion (e.g., computer, not computeer), and letter substitution (e.g., happiness, not happyness)). Somehow, readers 'see through' these orthographic variations (c.f., McCormick et al., 2008; Taft, 1979) to recover a word's morphological structure.

A third constraint, which is the focus of the present study, is that the coding of letter position is surprisingly imprecise. Models of word recognition have typically assumed that the input to the recognition process provides accurate information about the order of the letters in a to-be-recognized word. For example, in the interactive activation model (McClelland & Rumelhart, 1981), each of a written word's letters is assigned to a separate bank of feature and letter detectors in a manner that perfectly preserves information about relative letter position. Because the slot-based approach is representative of the assumptions made by most computational models of word recognition, recent evidence (e.g. Andrews, 1996; Perea and Lupker, 2003, and numerous other studies) of uncertainty in the representation of letter-position information has garnered a great deal of attention.

Of the various sorts of evidence suggesting that position information is coded imprecisely, the phenomena of most relevance to the present study are *transposed-letter similarity effects*. Collectively, these phenomena reveal that a given letter string is psychologically more similar to a letter string formed by transposing two of its letters (e.g., JUDGE/JUGDE) than a letter string formed by replacing those two letters with two other letters (e.g., JUDGE/JUPBE). For example, in the lexical decision task responses to transposed-letter (TL) nonwords such as JUGDE are slower and less accurate than responses to replaced-letter (RL) nonwords such as JUPBE (Chambers, 1979; Frankish & Turner, 2007). Conversely, in the masked priming paradigm, the response to a target word is faster and more accurate if it is preceded by a TL prime rather than an RL prime (Forster et al., 1987; Perea & Lupker, 2003). These results are inconsistent with the slot-based approach, which predicts no difference between the RL and TL conditions, and more generally, they reveal imprecision in the coding of letter position information (see Grainger, 2008, for a review of TL effects and their implications).

Of particular interest here is whether and how uncertainty about letter position modulates the influence of morphological structure on word recognition. For theories positing that morphological structure is only relevant to processes occurring *after* the activation of whole-word representations (e.g. Giraudo & Grainger, 2001; Lukatela et al., 1980), letter position uncertainty should be of no particular consequence to the processes that abstract and use this structure. Thus, although letter transpositions might have an impact on the processes by which whole-word representations are accessed, this effect would be the same regardless of a word's morphological status or the relationship between the position of the transposed letters and the boundaries between a word's constituent morphemes. In contrast, for theories positing an early influence of morphological structure, letter transpositions could be highly disruptive to morphological decoding, provided that the processes that extract morphological structure depend on precise letter position information. This would be the case, for example, if the parsing of a word into its morphological constituents is driven by the presence of letter sequences that are either highly familiar (Perruchet & Vintner, 1998; Taft, 1994) or low in probability (Rastle et al., 2004; Seidenberg, 1987). On the other hand, if the recognition of

whole words can tolerate variations in letter order, perhaps the same is true of the recognition of individual morphemes. This could be the case, for example, if morphemes are represented using one of the coding schemes (e.g. Davis, 1999; Grainger & van Heuven, 2003; Whitney, 2001) that has been used to account for letter transposition effects more broadly.

To date, only a handful of studies have investigated the impact of letter transpositions on morphological decomposition. The first of these was conducted by Christianson et al. (2005), who asked whether the transposed-letter similarity effect is modulated by the relation of a morphemic boundary to the position of the transposed letters. In one of their experiments, they included both morphologically complex English words such as BOASTER and pseudosuffixed words such as BLUSTER as target words in a masked priming task.¹ The primes were of three types: TL primes (BOASETR, BLUSETR), RL primes (BOASLER, BLUSLER), and identity primes (BOASTER, BLUSTER). Different patterns of results were found for the two target types. For the pseudoderived targets (BLUSTER), identity and TL primes facilitated naming latencies to the same degree (relative to the RL condition, which serves as the baseline condition in this type of experiment). In contrast, for morphologically complex targets (BOASTER), identity primes again facilitated naming, but TL primes did not: statistically, there were no differences in response times in the TL and RL conditions. Christianson et al. interpreted this pattern of results, which we will refer to as the *boundary effect*, as evidence that letter transpositions disrupt the process by which morphologically complex words are decomposed—a process that is relevant to the identification of multimorphemic words such as BOASTER but not pseudosuffixed words such as BLUSTER. Consistent with this interpretation, Christianson et al. (2005) also found boundary effects with compound-word targets: Primes formed by the transposition of letters across a morpheme boundary (SUNSHINE-SUSNHINE) yielded less facilitation than primes formed by either the transposition of letters within the same morpheme (SUNSHINE-SUNHSINE) or across a syllabic boundary that is not also a morphemic boundary (SACRASM-SARCASM).

Boundary effects have also been reported by Duñabeitia, Perea and Carreiras (2007). Duñabeitia et al.'s first experiment investigated TL priming with Basque suffixed derivations; two other experiments studied TL priming with both prefixed and suffixed Spanish derivations. In all three experiments, Duñabeitia et al. found facilitation from TL primes if the transpositions involved letters from the same morpheme but not if the transposition crossed a morphemic boundary. Thus these results, like those of Christianson et al. (2005), provide evidence not only that morphological decomposition occurs early in the process of word recognition, but also that the decomposition process is disrupted by letter transpositions that cross morphemic boundaries.

If accepted, the latter conclusion would place an important new constraint on models of morphological decomposition. However, several considerations suggest that we should be cautious in coming to this conclusion. First, in contrast to Christianson et al. (2005) and Duñabeitia et al., Perea and Carreiras (2006a) found no effect of morphemic boundary in a TL priming experiment using Basque compound and non-compound words. In their experiment, TL primes yielded significant facilitation regardless of whether the transposition crossed a morphemic boundary or not. Second, many of the studies investigating TL effects have used relatively long words, and thus have likely included morphologically complex words in the materials. For example, of the 35 TL primes in one condition of Lupker et al.'s (2008) second experiment, nearly half involved transpositions that crossed morphemic boundaries (e.g., APOLOGIZE- APOLOZIGE, REFLEXIVE-REFLEVIXE, MOVABLE-

¹BLUST is not a morpheme in English, and hence BLUSTER is not decomposable as BLUST + ER.

MOBAVLE, SOLVABLE- SOLBAVLE). While it is possible that the large (34 ms) priming effect in this condition was driven entirely by the remaining half of the items, it is equally plausible that this priming effect was due in part to facilitation from between-morpheme TL primes. Finally, as Perea and Carreiras (2006a) noted, several of the critical comparisons in the Christianson et al. results were not statistically significant. Moreover, due in part to selection constraints, these experiments involved a small number of relatively unfamiliar words.

Given these considerations, further investigation of the impact of letter transpositions on morphological processing is needed. The experiments reported below examined the effects of letter transpositions on the processing of English derived words, and are thus most closely related to Christianson et al. (2005)'s third experiment. However, our experiments differ from theirs in several key respects, reflecting both the concerns noted above and certain differences between their methodology and the methods more typically used to investigate the role of morphological structure in word recognition. Thus, like Christianson et al., we also used the masked priming paradigm, but the 42 ms stimulus onset asynchrony (SOA) used here is more representative of recent studies of masked morphological priming than the 100 ms SOA used by Christianson et al. Similarly, whereas Christianson et al. used a naming task, the task in our experiments was lexical decision—a much more commonly used task in both letter transposition and morphological priming experiments. The target words in our first three experiments were the roots of the derived-word primes (e.g. TEACHER-TEACH). To our knowledge this sort of prime-target relationship has not been used in studies of TL priming, but it is typically used in the morphological processing literature (e.g., Feldman, 2000; Murrell & Morton, 1974; Rastle et al., 2004, among many others) to ensure that priming effects are specifically related to morphological rather than orthographic similarity. This is of particular concern given that many of the experiments demonstrating boundary effects involved the comparison of conditions with morphologically complex and pseudomorphological targets (e.g. BOASTER vs. BLUSTER). Because these conditions can differ in both baseline measures and the magnitude of identity priming, it is possible that the differential effects of TL primes are due to factors other than the disruption of morphological decomposition. Relatedly, in our experiments the same derived words were used to create primes containing transpositions that did or did not cross a morpheme boundary, allowing us to avoid using pseudoaffixed forms like BLUSTER (a point we return to in the General Discussion).

The goal of our experiments was to evaluate two empirical hypotheses suggested by the results of Christianson et al. (2005) and Duñabeitia et al. (2007). The stronger hypothesis is that the facilitative effect of a transposed-letter prime is eliminated when the transposition crosses a morphemic boundary. The weaker hypothesis is that there is less priming when the transposition crosses a morphemic boundary than when the transposed letters are constituents of the same morpheme. Either hypothesis, if confirmed, would place important constraints on theoretical accounts of the process that extracts information about morphological structure from a written word.

Experiment 1

The goals of Experiment 1 were twofold. One was to establish that the facilitative effect of within-morpheme TL primes includes a morphological component. In previous studies (Christianson et al., 2005; Duñabeitia et al., 2007; Perea & Carreiras, 2006a) the target words were identical to the base forms of the within-morpheme TL primes, leaving open the possibility that the priming effects observed in these experiments were not a consequence of morphological processing per se, but instead reflect the same consequences of whole-word orthographic similarity that give rise to TL priming in monomorphemic words. Thus, the

target words in Experiment 1 (and several of the experiments that follow) were the roots of the derived-word primes (e.g. TEACHER-TEACH). To our knowledge this sort of prime-target relationship has not been used in studies of TL priming, but it is typically used in the morphological processing literature (e.g., Feldman, 2000; Murrell & Morton, 1974; Rastle et al., 2004, among many others) to ensure that priming effects are specifically related to morphological rather than orthographic similarity.

The second goal of Experiment 1 was to develop the methodology that would then be used to investigate the effects of transpositions that cross morphemic boundaries. In particular, our plan was to compare the effects of within- and across-morpheme transpositions of the same base words. Given the inventory of English suffixes and other characteristics of English orthography, transpositions that cross a morphemic boundary often involve a consonant and a vowel (e.g. TEACHER –TEACEHR). This is especially true if the transpositions involve adjacent letters (the condition that gives rise to the strongest TL effects, see Gomez et al., 2008; Perea, Duñabeitia, & Carreiras, 2008) and if orthographic alterations of the constituent morphemes (e.g., letter doubling) are to be avoided. Because the impact of vowel/consonant status on TL effects is somewhat unclear (cf. Perea & Lupker, 2004; Lupker et al., 2008), in Experiment 1 we included within-morpheme TL primes with vowel-consonant (VC) and consonant-consonant (CC) transpositions (e.g. SPEAKER-SPEKAER and TEACHER –TEAHCER, respectively). We expected that the results associated with this manipulation would provide guidance for the selection of stimuli for the subsequent experiments. For example, if primes with VC transpositions produced little or no facilitation, in subsequent experiments we would have elected to avoid the use of suffixes beginning with a vowel.

Method

Participants—Forty-five undergraduate students enrolled in an introductory psychology course at University of Connecticut participated in the experiment for course credit. All of the participants were native speakers of American English.

Design and Materials—The materials included 114 target words chosen from the English Lexicon Project database (Balota et al., 2007). For each target word, three primes were selected. In the *morphological* condition the prime was a morphological derivation of the target (e.g. teacher-TEACH or speaker-SPEAK). In the *transposed-letter (TL)* condition the prime was constructed by transposing the last two letters of the root morpheme (e.g. teahcer-TEACH or spekaer-SPEAK). (To contrast this condition with one from Experiments 2 and 3, we will refer to this as the *TL-within condition*, where “within” is used to indicate that the transposed letters belong to the same morpheme.) Finally, in the *replaced-letter (RL)* condition the two transposed letters in the TL-within condition were replaced with other letters, with the constraint that vowels were replaced by vowels, consonants by consonants, ascenders by ascenders, and descenders by descenders (e.g., teakser-TEACH and spefuier-SPEAK).

As discussed above, we also manipulated the consonant/vowel (CV) structure of the primes and targets. In the CC condition the last two letters of the target were both consonants (e.g. TEACH) and hence the TL-within primes involved the transposition of two consonants (e.g. TEACHER –TEAHCER). In contrast, in the VC condition the target words ended in a vowel-consonant sequence and thus the TL-within primes involved the transposition of a vowel and a consonant (e.g. SPEAKER –SPEKAER). The targets and morphological primes in the CC and VC conditions were matched on variety of factors using the English Lexicon Project database (Balota et al., 2007). These included the Kucera-Francis (1967) word frequency of both the targets (72.1 and 80.7 in the CC and VC conditions, respectively) and

primes (10.2, 22.3), target length (5.1, 4.9), prime length (7.3, 7.3), target orthographic neighborhood (5.3, 4.3), prime orthographic neighborhood (2.1, 1.5), target phonological neighborhood (11.1, 11.7), prime phonological neighborhood (3.7, 4.2), mean target bigram frequency (1890.9, 1680.2), mean prime bigram frequency (2386.5, 2248.0), mean target bigram frequency by position (1503.3, 1324.4), and mean prime bigram frequency by position (2524.3, 2352.6) ($p > 0.5$ for all comparisons). However, as would be expected given the orthotactic structure of English, the frequency of the critical bigrams (i.e., the letter pairs that were transposed or replaced) was lower in the CC condition than in the VC condition (2477, 3775, $p < 0.05$). For counterbalancing purposes, the targets in both the CV and CC conditions were partitioned into three sublists, with each sublist assigned to each priming condition equally often across subjects. The primes and targets are listed in Appendix 1.

The materials also included 114 nonword prime-target pairs. To match the words and nonwords on length, morphological suffix and other properties, each nonword target was created by changing two or more letters from one of the word targets. “Morphological” primes were constructed by combining a nonword with the suffix used with the corresponding target word, and transposed- and replaced-letter primes were constructed accordingly. The assignment of nonwords to priming conditions was counterbalanced using the same technique employed with the words.

Procedure—Participants were tested individually in a quiet room. After providing informed consent, they were told that they would see a number of letter-strings on the computer screen and that they would be required to decide whether the displayed letter string was a real word or not. The presence of the prime was not mentioned. The participants were asked to respond as quickly and accurately as possible and completed 20 practice trials before the block of 228 critical trials was administered. On each trial, a forward mask (a row of hash marks: #####) was displayed at the center of the computer screen for 500 ms. The mask was immediately followed by the prime, presented in lower case for 48 ms., which was in turn replaced by the target word, which was presented in upper case and remained on the screen for 1500 ms or until a response was made. The forward masks, primes and targets were all presented against a white background in black 18 point Courier New font. The intertrial interval was 1000 ms. A break was provided after half the trials were completed. The trials were presented in a random order with stimulus presentation and data collection controlled by E-Prime software running on a Pentium-4 processor connected to a CRT monitor.

Results

For reaction time (RT) analyses data from incorrect responses and from those responses that were faster than 250 ms or slower than 1500 ms (0.06% of data) were removed. In addition, the data from three target words that were mistakenly presented during the practice trials were also discarded. Table 1 displays mean RTs, the standard deviation of the means, and error rates for each condition.

Mean RTs were analyzed using 3 (priming condition) $\times$ 2 (CV structure) analyses of variance (ANOVAs), with priming condition considered a within-subject and within-item factor and VC structure a within-subject and between-item factor. The effect of priming condition was significant by both participants and items, $F_1(2, 88) = 27.04$, $MSE = 14845.98$, $p < 0.001$; $F_2(2, 218) = 19.712$, $MSE = 18648.78$, $p < 0.001$. Neither the effect of CV structure nor the interaction between these factors was significant. Pairwise comparisons (collapsing over CV conditions) revealed that each of the priming conditions were significantly different from each of the others ($p < 0.001$ by both subjects and items). Thus,

relative to the RL condition, there was significant facilitation in both the morphological and TL-within conditions (26 and 14 ms, respectively), with more benefit from the morphological primes.

Because the error rates were low and pattern of errors generally reinforce the conclusions drawn from the RT analyses, statistical analyses of the error rates (here and the subsequent experiments) are not reported.

Discussion

Three aspects of the results deserve some comment. First, we observed significant priming from within-morpheme TL primes. Although we did not include the orthographic control condition (e.g. card-CAR, brothel-BROTH) that is sometimes included in morphological priming experiments (e.g. Murrell & Morton, 1974; Rastle et al., 2004), the fact that the targets were morphological relatives of primes (but not identical to their base forms) suggests that there is a specifically morphological component to the priming in this condition. Second, it is noteworthy that there was significantly less priming in the TL-within priming condition than in the morphological priming condition. However, given the results reported below, we are not prepared to conclude that morphological priming is necessarily weakened by within-morpheme letter transpositions. Finally, similar patterns of results were obtained in the CC and VC conditions. Thus, both conditions were included in the experiments that follow.

Experiment 2

Experiment 2 asked whether TL priming is disrupted when the transposed letters cross a morphemic boundary. The method was similar to that of Experiment 1, except that the TL-within primes were replaced by TL-between primes formed by transposing the last letter of the root and the first letter of the suffix (e.g., TEACEHR, SPEAEKR).

Method

Participants—Forty-eight undergraduate students enrolled in an introductory psychology course at University of Connecticut participated in the experiment for course credit. All of the participants were native speakers of American English.

Design and Procedure—The primary difference between Experiments 1 and 2 pertained to the structure of the TL primes. In Experiment 1 the TL primes were constructed by transposing the last two letters of the root. In Experiment 2 the TL primes were constructed by transposing the last letter of the target and the first letter of the suffix (e.g. teacehr-TEACH, speaekr-SPEAK). We will refer to this as the *TL-across* condition. The critical bigrams in the CC and VC conditions (consonant-vowel bigrams in both cases) were matched in frequency (3755, 3205, $p > .20$). In all other respects the design, materials, and procedure in Experiment 2 was identical to that of Experiment 1.

Results and Discussion

As in the previous experiment, data from incorrect responses and from those responses that were faster than 250 ms or slower than 1500 ms (0.17% of data) were removed from the RT analyses. In addition, due to a programming error the data for one target word (SKEW) were also discarded. Mean RTs and error rates are presented in Table 2 as a function of priming condition and CV structure.

The data were analyzed in a similar manner as in Experiment 1. The effect of priming condition was significant by both participants and items, $F_1(2, 94) = 18.59$, $MSE =$

11567.03, $p < 0.001$; $F_2(2, 222) = 14.94$, $MSE = 13931.57$, $p < 0.001$. Neither the effect of CV structure nor the interaction between CV structure and priming condition was significant. Pairwise comparisons of the priming conditions (collapsing over CV condition) revealed that RTs in the RL condition were significantly slower than RTs in the morphological and TL-across conditions ($p < 0.001$ by both subjects and items for both comparisons). In contrast, the difference between the morphological and TL-within conditions was not statistically reliable. Thus, relative to the RL condition, there was equivalent facilitation for the morphological and TL-across conditions.

The results of Experiment 2 clearly refute the strong hypothesis that TL priming is eliminated when the transposed letters cross a morphemic boundary. Indeed, the fact that the magnitude of priming in the TL-across and morphological conditions was statistically equivalent suggests that the relation of the morphemic boundary to the position of the transposed letters had no impact whatsoever. The next experiment provides a stronger test of this conclusion.

Experiment 3

In Experiment 3 we sought to replicate the previous experiment's finding of facilitation from primes formed by transposing letters across a morphemic boundary. More importantly, we sought to directly compare the effects of letter transposition that do or do not cross a morphemic boundary. To this end, the priming conditions in Experiment 3 included both the TL-within condition from Experiment 1 and the TL-across condition from Experiment 2.

Method

Participants—The participants were 36 undergraduate students enrolled in an introductory psychology course at University of Connecticut and participated in the experiment for course credit. All of the participants were native speakers of American English.

Design and Procedure—The materials included the 114 target words from the previous experiments, as well as the TL-within and TL-across primes used in Experiments 1 and 2, respectively. To facilitate counterbalancing, six additional sets of targets, TL-within and TL-across primes were also constructed. In the CC condition, the frequency of the critical bigrams was lower in the TL-within condition than in the TL-across condition (2477, 3755, $p < 0.05$); in contrast, in the VC condition the critical bigrams were matched in frequency (3775, 3205, $p > 0.25$). Because different RL primes were used in Experiments 1 and 2 (as a consequence of their relation to the TL primes), in Experiment 3 the RL primes were constructed by replacing the last two letters of the target and the first letter of the suffix by other letters, again with the constraint that vowels were replaced by vowels, consonants by consonants, ascenders by ascenders, and descenders by descenders. Thus, for the targets TEACH and SPEAK the morphological primes were TEACHER and SPEAKER, the TL-within primes were TEAHCER and SPEKAER, the TL-across primes were TEACEHR and SPEAEKR, and the RL primes were TEARDIR and SPEIFUR. The items were partitioned into four sublists and rotated across conditions such that each target was presented in each priming condition equally often across participants. The procedure was identical to that of Experiments 1 and 2.

Results and Discussion

Data from incorrect responses and from those responses that were faster than 250 ms or slower than 1500 ms (0.16% of data) were removed from the RT analyses. Mean RTs and error rates are presented in Table 3. The RT data were analyzed using 4 (priming condition) $\times$ 2 (VC structure) ANOVAs. In these analyses, the effect of priming condition was

significant by both participants and items, $F(3, 105) = 9.73$, $MSE = 9029.30$, $p < 0.001$; $F(3, 354) = 7.83$, $MSE = 15225.58$, $p < 0.001$. Neither the effect of CV structure nor its interaction with the effect of priming condition was significant. Among the pairwise comparisons (collapsing over CV conditions), only the contrasts involving the RL condition were significant ($p < 0.05$ by both subjects and items). Thus, relative to the RL condition, there was equivalent facilitation for the morphological, TL-within as well as TL-across conditions (27 ms, 18 ms and 18 ms, respectively).

In sum, Experiment 3 provides no evidence that the effect of a TL prime depends on the relationship between the transposed letters and a morphemic boundary: Responses were facilitated to the same extent regardless of whether the transposed letters were constituents of the same morpheme or crossed a morpheme boundary.

Experiment 4

As noted in the Introduction, both Christianson et al. (2005) and Duñabeitia et al. (2007) reported facilitative effects of TL primes formed by transposing letters from the same morpheme but not from primes involving transpositions that crossed a morphemic boundary. Our experiments yielded a different pattern. We found that responses were facilitated by TL-across primes, and indeed, this facilitation was of the same magnitude as that produced by TL-within primes.

There are a variety of methodological differences between our experiments and those of Christianson et al. (2005) and Duñabeitia et al. (2007). One prominent difference concerns the relationship between the target words and the words used to generate the TL primes. The targets in the Christianson et al. and Duñabeitia et al. studies were identical to the base forms of the TL primes (as is typically the case in investigations of letter transposition effects). In contrast, following a strategy often used to study the influence of morphology on word recognition, the targets in our experiment were the roots of the suffixed words used to construct the TL primes. Thus, because two of the root letters were transposed in the TL-within primes and only one of the root letters (the final one) changed position in the TL-between primes, target words shared more letters (in the same position) with the TL-between primes than the TL-within primes. The purpose of Experiment 4 was to ask whether this difference might underlie the differences between our results and those of Christianson et al. and Duñabeitia et al.

Method

Participants—The participants were 40 undergraduate students enrolled in an introductory psychology course at University of Connecticut and participated in the experiment for course credit. All of the participants were native speakers of American English.

Design and Procedure—The only difference between Experiments 3 and 4 is that in Experiment 4 the targets were the suffixed words that were used as the morphological primes in Experiment 3. Consequently, the condition in which those suffixed words were presented as primes will be referred to as the “identity” priming condition. In all other respects, the methodology of Experiment 4 was identical to that of Experiment 3.

Results and Discussion

Mean RTs and error rates are presented in Table 4. As in the previous experiment, errors and outliers (2.58% of the trials) were removed from the RT analyses, and the data were analyzed using 4 (priming condition) $\times$ 2 (VC structure) ANOVAs. The effect of priming condition was significant by both participants and items, $F(3, 114) = 10.96$, $MSE =$

10347.41, $p < 0.001$; $F_2(3, 354) = 7.65$, $MSE = 18532.43$, $p < 0.001$. Neither the effect of CV structure nor its interaction with the effect of priming condition was significant. Pairwise comparisons revealed that responses in the RL condition were significantly slower than those in the identity, TL-within, and TL-across conditions ($p < .05$ by both subjects and items). RTs in the TL-within condition were not significantly different from those in either the identity or TL-across conditions. However, the difference between identity and TL-across conditions was statistically reliable ($p < .05$ by subjects and by items).

Thus, the present results are consistent with those of Experiments 2 and 3 in demonstrating facilitation from primes formed by transposing letters across a morphemic boundary. In this respect our results differ from those of Christianson et al. (2005) and Duñabeitia et al. (2007) and this difference does not appear to be attributable to differences in how the targets were constructed. With regard to the comparison of the TL-within and TL-across primes, our results are somewhat equivocal. The direct comparison of these conditions was not statistically significant; however, whereas responses in the TL-across condition were significantly slower than responses in the identity condition, the difference between the identity and TL-within conditions was not statistically reliable. Thus, while our results do not provide strong support for the conclusion that transposed-letter priming is modulated by the relation between the transposed letters and a morphemic boundary, these results do not provide unambiguous support for the alternative hypothesis either.

Experiment 5

Given the somewhat equivocal results of Experiment 4, we decided to run it again, but this time with a longer SOA. The change in SOA was motivated by the fact that both Christianson et al. (2005) and Duñabeitia et al. (2007) found boundary effects using longer SOA's (100 and 66 ms, respectively) than our own, whereas Perea and Carreiras (2006) used an SOA similar to ours and also failed to find an effect of the position of the morphological boundary on TL priming. Thus, it seemed possible that increasing the SOA in Experiment 5 (from 48 to 80 ms) would yield a pattern of results more similar to those of Christianson et al. (2005) and Duñabeitia et al. (2007).

Method

The method was identical to that of Experiment 4 except for the longer SOA (80 ms).

Results and Discussion

The results are presented in Table 5 and were analyzed in the same way as in Experiment 4. As before, the effect of priming condition was significant by both participants and items, $F_1(3, 117) = 55.24$, $MSE = 58422.42$, $p < 0.001$; $F_2(3, 354) = 35.98$, $MSE = 90253.31$, $p < 0.001$. Neither the effect of CV structure nor its interaction with the effect of priming condition was significant. Pairwise comparisons revealed that responses in the RL condition were significantly slower than those in the identity, TL-within, and TL-across conditions ($p < .001$ by both subjects and items). There were no differences among the identity, TL-within, and TL-across conditions in the analysis by participants, although in the items analysis responses in the TL-within condition were significantly slower than those in the identity condition ($p < 0.05$).

The implications of Experiment 5 are twofold. First, the results of Experiment 4 were somewhat ambiguous in that the direct comparison of the TL-within and TL-across conditions was not statistically significant, but only the TL-across condition was different from the identity condition. Experiment 5 resolves this ambiguity—there was no hint of a boundary effect in the present experiment. Second, although previous experiments yielding evidence of a boundary effect (Christianson et al., 2005, and Duñabeitia et al., 2007)

employed longer SOA's than those where a boundary effect was not found (Perea & Carreiras, 2006, and Experiments 1-4 here), the results of Experiment 5 do not support the hypothesis that SOA is the key methodological factor underlying these differences in results.

General Discussion

The processing of a target word is facilitated when it is preceded by a prime formed by transposing two of its letters. Previous research suggests that this effect is eliminated if the transposed letters cross a morphemic boundary, but not if the transposition is in a pseudoaffixed word or within a single morpheme of a multimorphemic word (Christianson et al., 2005; Duñabeitia et al., 2007). This pattern of results has been taken as evidence that cross-boundary transpositions disrupt the morphological decomposition process that occurs early in the course of recognizing a word.

The purpose of the present study was to investigate three issues raised by these findings. First, is morphological decomposition disrupted by within-morpheme letter transpositions? The fact that these earlier studies found facilitative effects of within-morpheme TL primes suggests not. However, because the primes and targets in these studies were identical (save for the letter transpositions), there is a possibility that the effects of within-morpheme TL primes occurred at the whole-word level. In our experiments the targets were morphologically related to, but not identical with, the base forms of the primes. Because priming under these conditions is based on the morphological relationship between the prime and target (Feldman, 2000; Rastle et al., 2004), the facilitative effects of the TL-within primes in our experiments provides strong evidence that morphological decomposition was not disrupted by these letter transpositions.

The second issue addressed by our experiments is whether primes formed by transposing letters across a morphemic boundary have any facilitative effect at all. Neither Christianson et al. (2005) nor Duñabeitia et al. (2007) found any evidence of facilitation from cross-boundary TL primes in affixed words, suggesting that the benefits of a TL prime are completely eliminated under these conditions. Our results disconfirm this hypothesis. Responses were faster following TL-across primes than RL control primes in each of the four experiments that included these conditions. In this respect, our results are similar to those of Perea & Carreiras (2006a) and Christianson et al.'s second experiment, where significant facilitation from TL-across primes was observed with compound word stimuli.

The third question addressed by our study concerns a weaker interpretation of the Christianson et al. (2005) and Duñabeitia et al. (2007) results: Is the effect of a TL prime diminished if the transposed letters cross a morphemic boundary? Our results suggest the answer is no. In Experiment 2 TL-across primes yielded as much priming as orthographically intact morphological primes, a finding that was replicated in Experiments 3. Furthermore, Experiments 3, 4, and 5 provided direct comparisons of the effects of TL-within and TL-across primes, and in none of these experiments was there an advantage for TL-within primes. These results support the conclusion that the relationship between a morphemic boundary and the position of two transposed letters is of no consequence for the word recognition process.

This being said, it should also be noted that we draw this last conclusion somewhat cautiously. First, unlike our other conclusions, this one rests on a null effect, and null effects are relatively weak forms of evidence. Second, and more importantly, while our results are in line with those of Perea & Carreiras (2006a), they differ from those of Christianson et al. (2005) and Duñabeitia et al. (2007), and the factors that underlie these differences remain unclear. One possibility we considered concerns the manner in which the within- and across-morpheme transpositions were constructed. One approach, taken by both Christianson et al.

(2005) and Duñabeitia et al. (2007), is to compare the effects of transposed-letter primes on the processing of morphologically complex words and monomorphemic words with similar spelling patterns. This approach allows for relatively precise control of the many variables that have been identified as possible modulators of transposed-letter effects.ⁱⁱ On the other hand, it is a strategy that greatly limits the number of potential stimuli and more importantly, it introduces other potential confounds. For example, Christianson et al. (2005, Experiment 3) compared TL priming effects for morphologically complex words such as BOASTER and pseudoaffixed (monomorphemic) words such as BLUSTER. A potential problem with this contrast is that pseudo-roots such as BLUST are unlikely to be seen as often or in as many contexts as actual roots such as BOAST, and it is not inconceivable that over the course of learning the repeated co-occurrence of a pseudo-root and a real affix changes the way in which that pseudoaffixed word is processed. (In this regard, it is noteworthy that baseline responses to the pseudoaffixed words in this experiment were substantially faster than responses to the morphologically complex words—616 vs. 656 ms—even though these words were matched on factors such as word and bigram frequency. Moreover, identity priming was much stronger for the pseudoaffixed words—72 vs. 45 ms—which is particularly surprising since all else being equal one would expect a larger priming effect in the condition with the slower baseline.ⁱⁱⁱ) The same-item approach taken in the present study offers a complementary set of strengths and weaknesses. Because the same target words appear in all conditions, the lexical and morphological properties of the targets are necessarily equated. On the other hand, because the comparison of within- and across-morpheme transpositions necessarily entails transposing different letters in each condition, precise control of letter and bigram properties is more difficult.

Could these differences between the same- and different-item methodologies explain why boundary effects have been found in some studies but not others? Probably not. While it is true that many of the experiments demonstrating boundary effects involved between-item comparisons (Christianson et al., 2005, Experiments 2 and 3; Duñabeitia et al., 2007, Experiments 1 and 2), boundary effects have also been observed using the same-item design (Christianson et al., 2005, Experiment 1; Duñabeitia et al., 2007, Experiment 3). Conversely, failures to observe boundary effects have also been reported using both approaches—same-items in the present study, and different-items in Perea & Carreiras (2006a).

At present we have been unable to identify a systematic difference between the studies that have found boundary effects and the studies that have not. Several of the more obvious candidates are listed in Table 6. As the table makes clear, the differences between the findings of the Christianson et al. (2005) and Duñabeitia et al. (2007) studies on the one hand, and those of Perea & Carreiras (2006a) and the present experiments on the other, cannot be readily attributed to differences in language, morphological formation, experimental task, SOA, or target type. For example, boundary effects have and have not been found in both English (found in Christianson et al., 2005, not found in the present study) and Spanish (found in Duñabeitia et al., 2007; not found in Perea & Carreiras, 2006a), and with both compound words (found in Christianson et al., 2005; not found in Perea & Carreiras, 2006a) and suffixed derivations (found in Christianson et al., 2005, and Duñabeitia et al., 2007; not found in the present study).

ⁱⁱThese variables include bigram frequency (Frankish & Turner, 2007; Perea & Carreiras, 2008), letter frequency (Lupker et al., 2008), letter position (Gomez et al., 2008; Perea & Lupker, 2004), pronounceability (Frankish & Turner, 2007), syllable structure (Lee & Taft, 2009), and language (Velan & Frost, 2007, 2009).

ⁱⁱⁱThis concern also applies to experiments employing monomorphemic words in which extant roots are concatenated with non-affix endings (e.g., BROTH/EL, QUART/Z). Baseline response times for conditions involving these words often differs from those for conditions involving seemingly well-matched morphologically complex words (cf. Feldman et al, 2009; McCormick et al., 2008; Rastle et al., 2004).

It is worth emphasizing that Table 6 is not an exhaustive list and that other methodological factors might be relevant to the influence of morphological structure on letter-transposition effects. For example, one reviewer suggested that boundary effects might be more likely to be found with shorter affixes—a suggestion that gains some plausibility from the fact that TL priming at the whole-word level is weaker for shorter words (Schoonbaert & Grainger, 2004)^{iv}. However, in this regard it is worth noting that the affixes of most of the primes used in the present study (93 of 120) were only two letters long—the length of the affixes in Christianson et al.'s (2005) third experiment. Thus, while affix length may well have an effect, it does not seem to be the explanation for the difference between Christianson et al.'s results and our own.

Another potentially relevant factor is bigram frequency. Several studies have reported more facilitation from primes formed by transposing low-frequency bigrams (Frankish & Turner, 2007; Perea & Carreiras, 2008) and morphemic boundaries are often marked by low-frequency bigrams (the *bigram trough* pattern, Seidenberg, 1987). Possibly, then, the morphemic boundary effect could be offset by the effect of bigram frequency on TL priming. Again, however, our data suggest otherwise. Although there was a difference in the frequency of the critical (TL-within and TL-across) bigrams in the CC condition there was no such difference in the VC condition, yet neither condition gave rise to a boundary effect. Moreover, in the CC condition the frequency of the critical bigrams was lower in the TL-within condition than in the TL-across condition; thus, if anything, this difference would have been expected to exaggerate, rather than diminish, the boundary effect.

To summarize, the present results suggest that readers extract morphological information from a transposed-letter prime, that morphological information is extracted even if the transposition crosses a morphemic boundary, and that whether the transposed letters crosses a morphemic boundary has no impact on the magnitude of facilitation—at least in the circumstances of the present experiments. Given that boundary effects have been found under other circumstances, more research is clearly needed to identify the factor or factors underlying these different patterns of results. As the empirical facts become clearer, we are likely to gain important insights about the time course of morphological processing and how morphological structure is extracted in the face of uncertainty about relative letter position. Indeed, coupled with recent findings concerning the effects of pseudomorphological structure (c.f., Feldman et al., 2009; Rastle et al., 2004) and variability in ortho-morphemic form (e.g., McCormick et al., 2008), evidence about the impact of positional uncertainty could provide interesting theoretical constraints on theories of morphological decomposition and (hopefully) foster the development of a new generation of computationally explicit models.

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Appendix 1

Each target word (capitalized) in Experiments 1-3 is followed by its (i) morphological prime, (ii) TL-within prime, (iii) TL-across prime, (iv) RL prime in Experiment 1, (v) RL prime in Experiment 2, and (vi) RL prime in Experiment 3. The stimuli in Experiment 4 and

^{iv}We thank Jon Andoni Duñabeitia for this suggestion.

5 were identical to those of Experiment 3 except that the morphological primes were also used as the targets.

CC Condition

ACCEPT acceptable accetpable acepatble accekjable accepikble acegehible; ACCIDENT accidental accidenatl accidenatl accidefral accidenokl accideskol; APPROACH approachable approachable approachable approachable approachable approachable; ATTACK attacker attacker attacker attacker attacker attacker; BANK banker bakner banekr balrer banutr bawfir; BLEND blender bledner blenedr bletwer blenilr blestor; BLOCK blockage blokage blokage blohrage blocutge blonfige; BOMB bomber bobmer bomebr bohver bomukr bortur; BOND bondage bodnage bonadge bokvage bonifge bovhuge; BOUND¹ boundary boudnary bounadry bouxkery; BOWL bowler bolwer bowelr botcer bowatr bockur; BUILD builder buidler builedr buikter builakr buitfar; BURN burner bunrer burenr buvcer burasr bucsir; CATCH catcher cathcer catcehr catkwer catcifr catwdur; CLIMB climber clibmer climebr clitser climotr clickor; COAST coastal coatsal coasatl coahral coasehl coavfil; CONTINENT continental continetnal continenatl continehcal continenubl continerkul; COUNT counter coutner counetr couhver counahr courdir; DESIGN designer desinger designr desicper desigacr desiyacor; DIRECT¹ director directcor directr direwhur; DRINK drinker drikner drinekr drihcer drinuhr dristur; FARM farmer famrer faremr fasver farisr faxwor; FAST faster fatser fasetr fakrer fasulr fawcir; FIGHT fighter figther fighetr figkler fighadr figlkor; FIRM firmer fimrer firemr fivcer firasr fisvur; FOREIGN foreigner foreinger foreigner foreisper foreigacr foreiqvar; FREIGHT freighter freigther freighetr freigkler freighuks freigflur; FRONT frontal frotnal fronatl frokwal fronuhl froskil; GROUND grounder grounder grounder grounder grounder grounder; HARVEST harvester harvetser harvesetr harvedner harvesifr harvenbur; HOLD holder hodler holedr hofter holitr hodtir; HUNT hunter hutner hunetr hudrer hunalr huxkir; LEARN learner leaner learner leawcer learicr leawcur; LEGEND¹ legendary legednary legenadry legetiry; LINK linkage liknage linakge lilrage linuhge lifrue; LOCK locker lokcer locekr lobser locutr lostir; MARK marker makrer marekr malcer marifr mavduer; PACK package pakage pacakge pahmage pacotge partuge; PAINT painter paitner painetr paihmer painobr paisfur; PLANT planter platner planetr plakcer planukr plavbir; POST postage potsage posatge pohrage posufge powkige; POTENT potential potetnal potenital potelwal potenihal potexfual; PREACH preacher preahcer preacehr prealmer preacikr preavkir; PRINT printer pritner prinetr pribcer prinalr priwdur; RENT rental retnal renatl relwal renufl recdil; SHARP sharper shaprer sharepr shaqwer sharujr shawjur; SHORT shortage shorage shoratge shodsage shoruhge shovkige; SHRINK shrinkage shrinkage shrinkage shrinkage shrinkage shrinkage; SING singer signer sinegr siprer sinayr siwqur; START starter statrer staretr stahwer starulr staxfor; STRETCH stretcher strethcer stretcehr stretbwer stretcacr stretdor; TALK talker takler talekr tadher talubr taftor; TANGENT tangential tangetnial tanekr tangelcial tanifr tangerhual; TANK tanker takner tangenital talner tangenual tasfir; TEACH teacher teahcer teacehr teakser teacifr teardir; THINK thinker thikner thinekr thidcer thinutr thivlur; TOAST toaster toatser toasetr toalcer toasuhr toawkir; TWIST twister twitser twisetw twikmer twisadr twicdor; WARM warmer wamrer waremr wacser waricr wawcur; WASH washer wahser wasehr watver wasikr wacur

VC Condition

ALCOHOL alcoholic alcohloic alcohloic alcohloic alcohloic alcohloic; ALLOW allowable allwoable alloawble allveable alloucble allurible; AVAIL available avaiable avaiable

¹Items used only in Experiment 3 and Experiment 4

avakuable avaihble avafuble; AVOID avoidable avodiabale avoiadble avotuabale avoiukble avouhuble; BETRAY betrayer betryaer betraeyr betrpeer betraigr betrugir; BLOW blower blwoer bloewr blmeer bloazr blevar; BOIL boiler bolier boiler bokeer boiahr boatur; BORROW borrower borroewr borroewr borrvuer borroucr borruvar; BREAK breakable brekaable breakable breluable breaihble breihuble; BROIL broiler brolier broielr brohaer broiatr broetar; CAPITAL¹ capitalize capitlaize capitailze capituhize; CLEAN cleaner clenaer cleaenr cleruer cleausr cleowur; COMMON commoner commnoer commoenr commier commouv commever; DEAL dealer delaer deaelr dekoer deauhr deihr; DRAIN drainage draniage draiange dravuge draiocge drausoge; DREAM dreamer dreaer dreaemr drevoer dreaovr dreusor; ENJOY enjoyable enjoable enjoayble enjeable enjoigle enjauble; FASHION fashionable fashinoable fashioanble fashiruabale fashiouable fashiucible; FEUD feudal fedual feudal febwal feuitl featol; FLOAT floater flotaer floaetr flodier floaehr floihir; FOLLOW follower follwoer folloewr follcaer folloacr follesir; GREAT greater gretaer greaetr greloer greaukr greukor; GROW grower grwoer groewr grmeer groicr gricar; HEAD header hedaer heaedr hetoer heaufr heutor; HEAL healer helaer heaelr hetier heaofr heufir; HEAR hearer heraer heaerr hesuer heaocr heimur; HEAT heater hetaer heaetr hekoer heaer heulir; JAIL jailer jaliar jaielr jadoer jaiutr jaehur; JOIN joiner jonier joienr jovaer joiusr jousar; LEAD leader ledaer leaedr lefuer leaitr leikur; LEAK leakage lekaage leaakge letuage leaobge leutige; LOAD loader lodaer loaedr lotier loaifr loifur; LOGIC logical logcial logiacl logroal logiuml logemul; MAGIC magical magcial magiacl magreal magierl magewol; MARGIN marginal margnial margianl margceal margiesl margesol; MARKET marketable markteable markeatable markduable markeifble markifible; MUSIC musical muscial musiacl musvoal musierl musevol; ORPHAN orphanage orphnaage orphaange orphwoage orphausge orphixuge; PATRON patronage patrnoage patroange patrsiange patrouvge patrusuge; PERSON personal persnoal persoanl perswual persouvl persicul; PIVOT pivotal pivtoal pivoatl pivkeal pivoexl pivedul; PLAY player plyaer plaeyr plguer plaugr plojur; PRISON prisoner prisnoer prisoenr priswaer prisoaxr prisecur; READ reader redaer reaedr reluer reautr reifor; REAP reaper repaer reaepr rejier reaojr reujir; REGION regional reginoal regioanl regimaal regioucl regiacul; SEASON seasonal seasnoal seasoanl seasvial seasoivl seasuril; SKEW skewer skweer skeewr skvoer skeovr skinur; SPEAK speaker spekaer speaekr spefuer speaehr spoutar; SPOIL spoiler spolier spoielr spodaer spoiutr speifur; STEAM steamer stemaer steaemr stecoer steauzr steucir; SUIT suitable sutiable sutiatble sukeable suiodble suakoble; SYMBOL¹ symbolize symbloize symboilize symbufaze; THROW thrower thrwoer thrower thrsoer throacr threacar; TOPIC topical topcial topiacl topmeal topierl topusul; TRAIN trainer tranier traienr trawoer traiuvr traovur; TROPIC tropical tropcial tropiacl tropwaal tropiuml tropewul; VIEW viewer viweer vieewr vinoer vieucr viusar; VISIT¹ visitor vistior visiotr visekar; WAIT waiter watier waietr wakuer waiokr waulor;

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TABLE 1
Mean reaction times (in milliseconds), standard deviations of the means, and error rates (% errors) in Experiment 1

CV Structure	Priming Condition							
	Morphological				TL-within			
	RT	SD	% Error	RT	SD	% Error	RT	SD
CC	545	57.98	1.88	558	58.85	2.74	573	63.54
VC	550	64.56	2.85	561	62.52	3.19	574	55.49

TABLE 2
Mean reaction times (in milliseconds), standard deviations of the means, and error rates (% errors) in Experiment 2

CV Structure	Priming Condition							
	Morphological				TL-within			
	RT	SD	% Error	RT	SD	% Error	RT	SD
CC	535	57.00	1.75	542	70.85	2.42	561	76.89
VC	544	68.50	2.69	545	61.47	3.36	560	63.64

TABLE 3

Mean reaction times (in milliseconds), standard deviations of the means, and error rates (% errors) in Experiment 3

		Priming Condition									
		Morphological					TL-within				
		TL-across					RL				
CV Structure	RT	SD	% Error	RT	SD	% Error	RT	SD	% Error	RT	% Error
CC	555	81.18	1.87	554	66.81	1.67	553	52.48	2.04	580	60.42
VC	543	62.15	2.78	561	61.81	2.99	562	72.04	4.07	571	54.36
											4.83

TABLE 4

Mean reaction times (in milliseconds), standard deviations of the means, and error rates (% errors) in Experiment 4

		Priming Condition									
		Identical					TL-within				
		TL-across					RL				
CV Structure	RT	SD	% Error	RT	SD	% Error	RT	SD	% Error	RT	% Error
CC	551	75.08	2.76	556	81.48	4.98	563	82.15	4.48	580	5.50
VC	558	88.76	3.60	559	76.98	3.76	566	85.81	3.93	580	5.69

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TABLE 6
Methodological comparison of past and present experiments investigating the interaction of letter transpositions and morphemic boundaries

Study	Language	Prime Type	Target Type ¹	Target Comparison ²	Task	SOA	Boundary Effect
<i>Christianson et al. (2006)</i>							
Expt 1	English	Compound	Complex	Same	Naming	100	YES
Expt 2	English	Compound	Complex	Different	Naming	100	YES
Expt 3	English	Derivation	Complex	Different	Naming	100	YES
<i>Perea & Carreiras (2006)</i>							
-----	Basque	Compound	Complex	Different	LD ³	47	NO
<i>Duñabedia et al. (2007)</i>							
Expt 1	Basque	Derivation	Complex	Different	LD	66	YES
Expt 2	Spanish	Derivation	Complex	Different	LD	66	YES
Expt 3	Spanish	Derivation	Complex	Same	LD	66	YES
<i>Rueckl & Rimzhim (present study)</i>							
Expt 1-3	English	Derivation	Root	Same	LD	48	NO
Expt 4	English	Derivation	Complex	Same	LD	48	NO
Expt 5	English	Derivation	Complex	Same	LD	80	NO

Notes:

¹Target words were morphologically *complex* (TEACHER) or the *root* morpheme of the prime (TEACH).

²Same or different targets used in the TL-within and TL-between conditions.

³LD = Lexical decision.