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TRANPOSED LETTER EFFECTS IN PREFIXED WORDS: IMPLICATIONS FOR MORPHOLOGICAL DECOMPOSITION¹

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Abstract

A crucial issue in word encoding is whether morphemes are involved in early stages. One paradigm that tests for this employs the transposed letter (TL) effect – the difference in the times to process a word (*misfile*) when it is preceded by a TL prime (*mifisile*) and when it is preceded by a substitute letter (SL) prime (*mintile*) – and examines whether the TL effect is smaller when the two adjacent letters cross a morpheme boundary. The evidence from prior studies is not consistent. Experiments 1 and 2 employed a parafoveal preview paradigm in which the transposed letters either crossed the prefix-stem boundary or did not, and found a clear TL effect regardless of whether the two letters crossed the morpheme boundary. Experiment 3 replicated this finding employing a masked priming lexical-decision paradigm. It thus appears that morphemes are not involved in early processes in English that are sensitive to letter order. There is some evidence for morphemic modulation of the TL effect in other languages; thus, the properties of the language may modulate when morphemes influence early letter position encoding.

There is now considerable evidence that morphological structure of a word influences the way in which it is processed, and in particular, that prefixes play a relatively early part in the encoding process. The landmark experiments of Taft and Forster (1975) employed the lexical decision task. One paradigm they employed was comparing nonword stems of prefixed words (e.g. *juvenate*) to nonword stems of pseudoprefixed words (e.g. *pertoire*). They found that it took longer to classify nonword prefixed stems as nonwords than the pseudoprefixed nonword stems indicating that the root morpheme, although not a word itself, had wordlike properties that made “nonword” decisions more difficult. They obtained similar results when an illegal prefix was added to the items (*dejuvenate/depertoire*). From these experiments, they argued that stripping the prefix from a prefixed word was an initial step in processing prefixed words.

Burani, Salmaso & Caramazza (1984) expanded on the Taft & Forster (1975) results using Italian prefixed and suffixed words. They manipulated the word and morpheme frequencies in a lexical decision task and found that participants were (a) quickest to respond “yes” to high frequency words with high frequency roots, (b) were less quick to respond “yes” to high frequency words with low frequency roots and (c) slowest to respond “yes” to low frequency words with low frequency roots. These results paralleled those of Taft and Forster (1975) because they confirmed that the root-morpheme frequency is a significant determinant of response times in lexical decision tasks. Morphemes also produce priming effects that are not merely a function of their orthographic similarity to the target. For example, Feldman (2001) observed a greater priming effect in a lexical decision task to targets preceded by a morphologically related word than to when they were preceded either

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an orthographically related control word or by a semantically related prime. All these results indicate that morphemes play a role in lexical access.

Morphemic effects in encoding words have also been studied in sentence reading employing eye movement measures. One paradigm that has been employed is to vary the frequency of component morphemes in morphemically complex words while holding the frequency of the whole word constant. The original experiments, which employed long compound words in Finnish (Hyönä & Pollatsek, 1998, Pollatsek, Hyönä, & Bertram, 2000), found large effects of the frequency of both the first and second constituents on the fixation time on the word (i.e., *gaze duration*). A later experiment in Finnish (Bertram & Hyönä, 2003), however, found no first constituent frequency effects on gaze duration for shorter Finnish compound words. Although the effects of constituent frequency in English are not as reliable as in Finnish, they have generally been found (e.g., Andrews, Miller, & Rayner, 2004, Juhasz, Starr, Inhoff, & Placke, 2003). Perhaps more to the point of the current research, however, is that root frequency effects have been found for English prefixed words, especially for words of over six letters (Niswander-Klement & Pollatsek, 2006) indicating that prefixed words are, at least to some extent, processed componentially in reading text.

A major unanswered question is how early in processing morphemes, as units, enter into the encoding of morphologically complex words. One indication of early involvement of morphemes in word identification in sentence reading is that the frequency of the first morpheme affected the duration of the first fixation on a word (Hyönä & Pollatsek, 1998). What has also been argued as a dramatic demonstration of early morphemic involvement was provided by Rastle, Davis and New (2004) using the masked priming paradigm of Forster & Davis (1984). They compared the priming of words composed of stem and suffix (e.g., *cleaner* as a prime for *clean*) to that for words composed of pseudostem and pseudosuffix (e.g., *corner* as prime for *corn*) and to that for words composed of pseudostem and nonsuffix (e.g., *brothel* as prime for *broth*). Lexical decision times in the first two conditions were significantly faster than in the third condition. The fact that the brief prime *cleaner* was effective indicated that morphemic occurred early. What was even more surprising was that *corner* primed *corn*. This suggests that the final *-er* was treated as morpheme in early stages of processing because *-er* is a common suffix even though it is not a suffix in *corner*, whereas the final *-el* in *brothel* was not because it is not a suffix. More broadly, it suggests that morphemes are activated, at least to some extent, before the lexical entry is activated. There is some controversy in this literature, however, about whether priming is better in the real suffix condition than in the pseudo-suffix condition (e.g., Feldman, O'Connor, Moscoso del Prado Martin, 2009).

These masked priming findings have stimulated research on how early morphemes are activated and enter into word identification, and in particular, how this relates to the letter encoding process. The letter encoding process – including how the positions of letters are encoded – has primarily been investigated by using words with two adjacent letters transposed (e.g., *jugde*). These transposed letter (TL) stimuli are usually compared to substitution letter (SL) controls (e.g., *jukpe*) in which the same two letters are replaced by other letters (for a review, see Perea & Lupker, 2003; Schoonbaert & Grainger, 2004). For example, in a lexical decision task, it is harder to judge TL nonwords as nonwords than than SL nonwords indicating that the TL nonwords are easier to confuse with the base word (Perea & Lupker, 2003). More relevant to the issue of the relative time courses of letter position encoding and morpheme identification, TL nonwords as primes (e.g., *judge*) facilitate encoding of the base word (e.g., *judge*) better than do SL nonwords (e.g., *jukpe*). This implies that the identities of letters must be computed in early stages of visual word recognition at least somewhat independently of letter position. These effects can be explained by a model of word encoding that allows letter position to be coded with random

error (e.g., Gómez, Ratcliff, & Perea, 2008). This TL effect has also been found using parafoveal previews during normal silent reading, so that it is not restricted to single word tasks (Johnson, Perea, & Rayner, 2008). We will refer to the faster processing times for target words when preceded by a TL prime than those when the target is preceded by a SL prime as “the transposed-letter (or TL effect)”.

Another phenomenon that would be evidence for an early morphemic involvement in word encoding is if transposed-letter effects differ depending on whether the transposed letters cross a morpheme boundary or not. That is, if morphological decomposition occurs at very early stages of word identification processes, then if the TL primes disrupt the morphemic structure of a word (e.g., *misfile* as a prime for *misfile*), the advantage of TL primes over SL may either be attenuated or disappear altogether. Thus far, there have been relatively few studies exploring this hypothesis. Dunabeitia, Perea, and Carreiras (2007) conducted a set of experiments using the lexical decision task comparing Spanish and Basque polymorphemic and monomorphemic words. Using TL and SL nonwords as primes, they positioned transpositions of adjacent letters or substitutions to occur within or across a morpheme boundary (e.g., the polymorphemic word ESCOM/BRO could be primed by TL *escobmro* or SL *escohcro*) (e.g., the prefixed word BIZ/NIETO could be primed by TL *binzieto* or SL *bicsieto*). They found a significant transposed-letter effect for non-affixed words but no transposed-letter effect across morpheme boundaries for either prefixed or suffixed words. However, Perea, Duñabeitia, Acha, and Carreiras (2007) did find the same sized TL effects in Spanish for suffixed and control words when the transposed letters had an intervening letter (e.g., *colodiro* as the TL prime for COLORIDO). In addition, Perea and Carreiras (2006) did not find an attenuation of the TL effect when the morpheme boundary was between two morphemes of a Basque compound word. In all cases, transposed-letter effects occurred for polymorphemic words for within-morpheme transpositions.

In English, there are also somewhat contradictory results about whether there the TL effect goes away or is attenuated when the transposed letters cross a morpheme boundary. On the one hand, Christianson, Johnson, and Rayner (2005) reported a morpheme effect on the transposed letter effect in English with suffixed items, using masked priming, but with a naming task rather than a lexical decision task. They compared targets containing the derivational suffix *-er* (e.g. *baker*) to targets containing the pseudo-suffix *-er* (e.g. *bluster*). The derivational items contained an English word plus a suffix whereas the pseudo-suffixed items did not contain an English word if *-er* is removed (e.g. *baker* is someone who bakes, but *bluster* is not someone who *blusts*). They found a significant T-L effect for pseudo-suffixed items (a 55 ms difference between SL prime and TL prime conditions) and a non-significant 12 ms TL effect for truly derived words; however, the interaction was not significant so this is weak evidence that crossing a morpheme boundary affects the TL effect¹. In contrast, Rueckl & Rimzhim (2010) found the same sized TL-effect for English suffixed words when the transposed letters crossed the boundary (e.g., *speaekr*) as for non-suffixed words. (This effect was replicated in five experiments.) In three, the paradigm was slightly different from those above, in that the prime was the suffixed word, but the target was the root word (e.g., *teacehr* -TEACH). However, in the other two experiments, the target was also the suffixed word.

These masked priming experiments thus do not present a clear picture. In English, where suffixes have been the sole morpheme unit studied to date, most of the evidence points to there still being a TL effect when the transposed letters of the prime when the transposed letter disrupt its morphemic structure. In Spanish, however, there is a somewhat different,

¹The Christianson et al. (2005) study had several other limitations: there were only had 12 items in their sample, one suffix, *-er*, and an unusual orthographic control (i.e., only one of the two letters was replaced in the SL condition).

but not completely coherent, pattern. That is, in one experiment, transposing adjacent letters in the prime that disrupted the morphemic structure between the root morpheme and the suffix produced no TL effect. However, in a second one, where the transposed letters were of non-adjacent letters, there was an undiminished TL effect when the TL prime disrupted the same morphemic structure. In another experiment, there was a reduced TL effect when the TL prime disrupted the prefix root-morpheme structure; however, in another experiment, there was no diminishing of the TL effect when the transposed letters crossed the boundary between the two morphemes of a compound word. In contrast, the evidence seems to be more consistent in Basque that disrupting the morphemic boundary of the prime disrupted the TL effect. However, Basque is not an Indo-European language, and there are reasons to believe that early involvement of morphemic analysis might be more pervasive than in languages like English and Spanish. We will return to the issue of differences across languages in the discussion section.

Given the somewhat mixed findings above, the goal of the present experiments was to determine whether the TL effect would be preserved in English even when the morphemic boundary being crossed was between the prefix and root morpheme. One reason for investigating the issue using prefixed words is that it is plausibly the strongest test of early morphemic involvement in letter encoding. First, there is the work cited above by Taft and Forster that suggests that encoding and stripping away prefixes is an important first step to encoding prefixed words. Second, we thought it was important to investigate the issue when people were reading prefixed words in text, rather than doing a lexical decision judgment. In Experiments 1 and 2, where the issue was studied in reading using the boundary paradigm (Rayner, 1975) instead of using a briefly presented prime, the “prime” was a parafoveal preview that was visible until the target word was fixated. Although this means that the preview stimulus was visible for an extended amount of time, processing a word before it is fixated is almost certainly the earliest stage of word identification in reading. Moreover, in this paradigm, as in masked priming, participants are virtually never aware either of the identity of the prime or of the display change.

Another reason for focusing on prefixed words using the boundary paradigm is that there is considerable evidence that the first few letters of a word in the parafovea have by far the largest effect on fixation time on a word when it is subsequently fixated (Rayner, 1998); Although TL effects have been obtained at the ends of words (Johnson, et al., 2008), we thought that the maximal TL effects would occur when letters near the beginning of a word were transposed and hence would have maximal power to detect an attenuation of these effects if the transposed letters crossed a morpheme boundary.

Another unique feature of Experiments 1 and 2 is that both lexicalized prefixed words and novel prefixed words (e.g., *miscircled*) were employed. This seemed to be the strongest test of early morphemic involvement in encoding because these novel words presumably have to be identified through morphemic decomposition. One piece of evidence for this is that gaze durations on novel prefixed words are considerably longer than for lexicalized prefixed words in which the root morphemes are equated on frequency (Pollatsek, Slattery, & Juhasz, 2008). As a result, transposing letters in the preview such that the prefix is no longer an orthographic unit should have a large detrimental effect on encoding such novel words. In addition, because these novel words are not at all predictable given the prior text, there is little chance that the identification process for them is facilitated by the prior context. Accordingly, we compared the size of the TL effect in Experiments 1 and 2 for both novel and lexicalized prefixed words when the transposed letters crossed a morpheme boundary with the TL effect for non-prefixed words when the transpositions were in the same location in that word but did not cross a morpheme boundary. In Experiment 3, we employed the masked priming paradigm (using the lexical decision task) to test whether the pattern of data

between our Experiments 1 and 2 would be the same when the “priming” stimulus was in the parafovea as when it was in the fovea. In all three experiments, identical previews or primes were also employed as a baseline condition to determine whether there was any cost to transposing the letters. For reasons we will explain later, Experiment 3 did not employ novel prefixed words as targets.

Experiment 1

In Experiment 1, the effects of a parafoveal preview manipulation were examined for (a) novel prefixed words (e.g. *miscentered*), (b) lexical prefixed words (e.g. *misapplied*), and (c) monomorphemic words (e.g. *modified*) during the reading of single sentences. There were three preview conditions: (a) *identical* – the preview that was visible prior to crossing the boundary was identical to the target; (b) *transposed letters (TL)* – two adjacent letters in the target were transposed (e.g., *micsentered/miaspplied,moidfied*); and (c) *substitute letters (SL)* – the same two letters in the target were replaced by other letters (e.g., *mizventered/mizepplied/molufied*).

Method

Participants—Forty-two undergraduate students from the University of Massachusetts of Amherst participated in the study for extra credit in their psychology courses. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

Apparatus and procedure—Participants were seated 60 cm from a color monitor. Three characters subtended one degree of visual angle. Eye movements were recorded with a SR Research Ltd. EyeLink 1000 eye tracking system that has high spatial resolution and a sampling rate of 1000 Hz. Viewing was binocular, but only the right eye was tracked. Sentences were presented on a single line in black letters against a white background in Courier New font so that all the characters had the same width. The letters were presented as in normal text, with lowercase and uppercase letters appearing where appropriate. Custom-built software controlled the presentation of the sentences and accomplished the display changes. The monitor refresh rate was set at 150 Hz to ensure the display changes were not detectable.

When participants arrived for the experiment, they were given a written description of the experimental situation and procedure followed by verbal instructions about the task. They were told they would read a series of sentences normally, for comprehension, on a computer screen while their eye movements were being monitored. Each participant read 10 practice trials, 36 experimental trials, and 70 filler trials. Approximately 20% of the sentences were followed by a comprehension question requiring a yes/no response made by pressing a button on a response box.

After instruction and informed consent, there was an initial calibration lasting about 5 minutes. After getting a good calibration, the participant was instructed to fixate on the leftmost calibration box, and the experimenter initiated the trial. When a sentence was initially presented, the initial fixation was on the first letter of the first word in the sentence. Initially, the target word was replaced with a preview, but once the participant’s eyes crossed an invisible boundary between the last two characters of the word immediately preceding the target word, the preview changed to the target word (see Figure 1). The target word then remained present until the participant indicated that he or she was finished reading the sentence. Participants were told to read each sentence silently and to press a button on a response box when they finished reading the sentence. Upon finishing the sentence, either a yes/no comprehension question appeared or the calibration screen reappeared. Under certain conditions, the display change can occur during fixation and thus

be visible to the participant. During debriefing, participants were asked to report what they noticed about the display changes.

Materials and design—There were 108 target words, with one word from each of the three target word conditions embedded in each of the 36 sentence frames. As indicated above, the three target word conditions were: (1) *novel prefixed* (e.g., *miscentered*), (2) *lexical prefixed* (e.g., *misapplied*), and (3) *lexical non-prefixed* (e.g., *modified*). Target words were never either the first or last word in the sentence. The Francis and Kucera (1982) frequency count was used as a measure of the root frequencies of the target words. Root frequencies ranged from 1 per million written words to 715 per million ($M = 77$). The mean length of the target words was 9.18 characters and did not differ among the three categories of words.

Each target word was placed in a neutral sentence context, preceded by at least two words. For each target word type, there were three preview conditions: (1) *identical* (e.g., *miscentered/modified*), in which the parafoveal preview was the same as the target word; (2) *transposed letter (TL)*, in which the parafoveal preview transposed the last letter of the prefix and the first letter of the stem (e.g., *miccentered/moidfied*); and (3) *substitute letter (SL)*, in which the parafoveal preview replaced the last letter of the prefix and the first letter of the stem (e.g., *mivcentered/molufied*). The replacement letters were chosen so that the overall letter shape was consistent with the original target word letters (i.e., ascending letters were replaced with ascending letters, descending letters with descending letters and neither ascending or descending letters with visually similar letters).

Results and Discussion

Ten participants were excluded from the analyses either because they were not native speakers of English or if they reported seeing the display change on majority of the trials. Data from individual trials of the remaining participants were excluded for any of the following reasons: (1) A track loss occurred; (2) the eyes triggered the boundary change but actually landed on the word prior to the target word; (3) the first fixation on the target word was less than 120 ms, or the first-pass fixation (gaze duration) was greater than 600 ms; or (4) the participant blinked on the pretarget word, target word or post-target word. When there were two fixations on adjacent letters and one of the fixations was short (less than 120 ms), they were counted as a single fixation. After data were excluded from the analyses according to the criteria above, 70% of the data remained. The mean correct response rate to the yes/no comprehension questions was 82%, which is not unreasonable given that the meaning of many of the novel stimuli was not completely unambiguous. Thus, it appeared that participants understood most of the sentences.

Standard eye fixation duration measures were computed to examine the manipulation of preview and word types in reading. These duration measures were *first fixation duration*, *gaze duration*, *go-past time* and *total time*. All these measures are conditional on the word being fixated on the *first pass* through the text (i.e., conditional on it not being skipped over initially). *First fixation duration* is the duration of the initial fixation on a word. *Gaze duration* is the sum of all fixation durations on a word on the first pass. *Go-past time* is the time between when a word is first fixated on the first pass and when it is exited to the right (i.e., it includes regressions back from the word). *Total time* is the mean of the sum of all fixations on a word (including regressions back to the word).

Experiment 1 had considerable data loss due to excluded trials. Using a standard analysis of variance, empty cells result in the dropping of all of that particular participant's data, thus causing a loss of power. To ensure that the effects reported above were robust, the data were examined using linear mixed models (LMM) with the lme4 package of Bates and Sarkar

(2007). Simulations were run in R (version 2.9.0) (R development core team, 2007). With LMM, missing cells do not result in the loss of an entire participant or an entire item because LMM uses participant, item and effect means to estimate the missing cell values. As a result, the analysis is generally more powerful than a standard ANOVA.

The primary comparisons of interest were (a) the *transposed letter effect*, the difference between the transposed letter (TL) and substitute letter (SL) conditions, and (b) the *preview effect*, the difference between the identical preview and SL conditions. The former difference assesses whether there is any benefit from the preview having the correct letters even when the order is not correct and the latter difference assesses the total benefit of the preview having the correct two letters in the correct position. Using the full model, with both word type (novel prefixed, lexical prefixed, lexical non-prefixed) and preview type (identical, transposed letter, substitute letter) as predictors, LMM provides t-values for the interaction effects. All effects were computed for the first fixation duration, gaze duration, go-past and total time measures. Using the LMM analysis in R, t-values are reported. Significance is calculated using a separate analysis (command “p-vals”) based on Markov chain Monte Carlo sampling. The significance level implies that both participants and items are each randomly sampled from populations.

As can be seen in Table 1, the pattern of data was quite straightforward. For first fixation duration, there was a 20 ms preview effect (averaged over the three target word conditions), $t = 2.93$, $pMCMC < .001$, and a 24 ms transposed letter effect, $t = 2.14$, $pMCMC < .05$. The transposed letter effect was 22, 34, and 16 ms for the novel prefixed word, lexicalized prefixed word, and non-prefixed word conditions, respectively, and the interaction of this effect with target word condition was far from significant, $t < 1$. Similarly, for gaze duration, there was a 35 ms preview effect, $t = 2.82$, $pMCMC < .01$, and a 41 ms transposed letter effect, $t = 3.30$, $pMCMC < .001$. The transposed letter effect was 52, 21, and 49 ms for the novel prefixed word, lexicalized prefixed word, and non-prefixed word conditions, and again the interaction with target word condition was far from significant, $t < 1$. For all measures in Table 1, the difference between the identical preview and TL preview conditions was far from significant ($ts < 1$). The differences for the later measures were about the same size as for gaze duration but somewhat less reliable as the data were more variable. For go past time, there was a 42 ms preview effect, $t = 2.58$, $pMCMC < .001$, and a marginally significant 33 ms transposed letter effect, $t = 1.78$, $pMCMC = .08$. The differences between the TL and SL conditions were 57, 20, and 23 ms for the novel prefixed word, lexicalized prefixed word, and non-prefixed word conditions, respectively, and again the interaction of this effect with target word condition was far from significant, $t < 1$. For total time, there was a 32 ms transposed letter effect, $t = 2.02$, $pMCMC < .05$; however, there was a 0 ms preview effect.

We were also interested in whether the large ‘novelty effect’ that was observed in Pollatsek, et al. (2008) would be replicated. These comparisons are of the differences between the novel and lexicalized prefixed words averaged over the three preview conditions as the prior analyses indicated no interaction of prefix condition with type of target. The 12 ms difference in first fixation duration was not quite significant $t = 1.93$, $p < .10$. However, the novelty effects on gaze duration, gopast time, and total time were all large and significant: 61 ms, 107 ms, and 144 ms, $ts = 4.78, 5.91, 6.89$, respectively, $ps < .001$.

Discussion

The results of Experiment 1 were quite clear, especially for the earlier measures, first fixation duration and gaze duration. For both these measures, there were clear transposed letter effects. In addition, on most measures, the transposed letter preview was virtually as effective as the identical preview (see also Johnson et al., 2008). Moreover, there was no

significant difference between when the transposed letters crossed the morpheme boundary and when they didn't. The only suggestion of a morpheme boundary effect was in gaze duration, but the effect was far from significant. (However, the effect was in the opposite direction for first fixation duration.) To guard against the possibility that the interactions were insignificant because of the inclusion of the novel target word condition, we examined the interaction of the transposed letter effect with the two (non-novel) target word conditions for the two earlier measures. For first fixation duration, after removing the novel prefixed words from the model, the 26 ms transposed letter effect was significant, $t = 3.01$, $pMCMC < .001$, but the interaction was not, $t < 1$. For gaze duration, the 35 ms TL effect was significant, $t = 2.81$, $pMCMC < .05$, but the interaction was not, $t < 1$. There also appeared to be a somewhat larger preview effect for the novel words than for the other two target word conditions. Although this would appear to be very strong evidence against morphemic analysis being important in early stages of word processing, one could perhaps construct an argument that this larger effect is related to the fact that these target words took significantly longer to process than those in the other two conditions.

The results of Experiment 1 do not support early decomposition theories as there was little evidence that destroying the integrity of the initial prefix morpheme in the parafovea matters. Moreover, this lack of difference between the prefixed and non-prefixed conditions was not due to a lack of power, as there was a clearly significant cost when the substituted letters were in the same locations. Although, the interaction was far from significant, there was a suggestion of an interaction in the gaze duration measure where the TL effect appeared to be greater for the novel prefixed words and the non-prefixed words than for the lexicalized prefixed words. Although this pattern was not observed in the other measures, we thought it would be advisable to attempt to replicate the experiment with what seemed to be a superior design that would result in less loss of data.

Experiment 2

In Experiment 1, the boundary was placed between the last and second-to-last character of the word right before the target word in an attempt to move the fixation prior to the boundary as far as feasible from the parafoveal information that was manipulated and thus to minimize the probability that participants would see the unusual preview. This boundary location, however, was "unorthodox" as most studies employing the boundary technique place the boundary just before the space before the target word (e.g., Johnson, Perea & Rayner, 2007; Kambe, 2004). In particular, the placement in Experiment 1 resulted in a large number of excluded trials and participants, because participants often fixated right at the boundary location, which made the display change visible. In Experiment 2, the boundary was moved to just before the space before the target word (see Figure 2). Other than that, Experiment 2 was identical to Experiment 1.

Method

Participants—Fifty-eight undergraduate students from the University of Massachusetts of Amherst participated in the study for extra credit in their psychology courses. All were native speakers of English and had normal or corrected-to-normal vision. They were all naïve to the purpose of the experiment.

Apparatus, procedure, materials, and design—As indicated above, these were all the same as in Experiment 1 except that the boundary location was moved one character space to the right. As a result, all participants reported seeing at most one display change, which was described as a "flicker."

Results and Discussion

Data and participants were excluded according to the same criteria as in Experiment 1, after this, 100% of the participants and 71% of the data remained. The average correct response rate to the yes/no comprehension questions was 85%. A major goal in conducting Experiment 2 was to reduce data loss. Although this goal was partially achieved as no participants were excluded from this analysis based on awareness of the display change, the data loss for the remaining participants was not improved: there was a 30% and 29% data loss in Experiments 1 & 2 respectively. In a set of similar display change experiments, Johnson et al. (2007) reported data loss for three experiments as 31%, 16% and 18%. Thus, data loss may be unavoidable in experiments using display changes where the changed material is so close to the boundary location.

The data replicated Experiment 1 quite closely (see Table 2). For first fixation duration, the preview effect was 15 ms (averaged over the three target word conditions), $t = 2.61$, $pMCMC < .01$, and the transposed letter effect was 15 ms, $t = 3.12$, $pMCMC < .001$. Again, there was no interaction between the transposed letter effect and the target word, $t < 1$, as the differences between the TL and SL conditions were 17, 13, and 16 ms for the novel prefixed word, lexicalized prefixed word, and non-prefixed word conditions, respectively. For gaze duration, the preview effect was 47 ms, $t = 4.20$, $pMCMC < .001$, and the transposed letter effect was 49 ms, $t = 4.41$, $pMCMC < .001$. The interaction with target word condition was not significant, $t < 1$, even though the preview effect seemed appreciably bigger for the novel prefixed words: the differences between the TL and SL conditions were 75, 42, and 30 ms for the novel prefixed word, lexicalized prefixed word, and non-prefixed word conditions, respectively.

The sizes of the effects were more or less the same for the later measures, but again were less reliable because there was more variability in these measures. For go-past, the 26 ms preview effect was marginally significant $t = 1.73$, $pMCMC = .08$, but the transposed letter effect of 37 ms was significant, $t = 2.47$, $pMCMC < .05$. For total time, the 20 ms overall preview effect was not significant, $t < 1$, and the 29 ms transposed letter effect was marginally significant, $t = 1.87$, $pMCMC = .06$. As in Experiment 1, an analysis of the transposed letter effect with only the lexical prefixed words and non-prefixed words was conducted. For first fixation duration, after removing the novel prefixed words from the model, the overall 18 ms transposed letter effect was significant, $t = 2.34$, $pMCMC < .05$, but the interaction was not, $t < 1$. For gaze duration, the overall 35 ms TL effect was significant, $t = 3.35$, $pMCMC < .01$, but the interaction was not, $pMCMC > .05$. The transposed letter effect was not significant in the later measures, $pMCMC > .05$, but was in the right direction. In go-past and total time, the size of the transposed letter effect was actually larger for prefixed words (38 ms for go-past, 47 ms for total time) than for non-prefixed words (17 ms for go-past, 11 ms for total time). This analysis replicates the comparison of lexical items in Experiment 1; the TL effect was significant regardless of lexical word type, with no significant interactions.

As in Experiment 1, we also examined the novelty effect on the prefixed words. Here, the effect was significant on all of the fixation duration measures. The novelty effects on first fixation duration, gaze duration, gopast time, and total time were all significant: 9 ms, 74 ms, 118 ms, and 147 ms, $t_s = 2.40, 6.79, 7.49, 8.90$, respectively, $p_s < .05, .001, .001, .001$.

Discussion and further analysis

The results of Experiment 2 obviously replicated those of Experiment 1 quite closely. The only notable difference was that there was a suggestion in Experiment 1 that the transposed letter effect was greater in the gaze duration measure for the non-prefixed words than for the

lexicalized prefixed words, but in Experiment 2, the effect went the other way (although neither effect was close to significant). Thus, the basic findings of both experiments were (a) there was a transposed letter effect that was virtually the same size as the preview effect and (b) that it was irrelevant whether the transposed letters crossed a morpheme boundary or not. The former result suggests that letter position coding in the parafovea may be quite inexact and thus be one reason why the results here differ from the ones in the masked priming studies in Spanish and Basque. This issue will be addressed in Experiment 3. However, we thought it would be of value to first present an analysis of the combined data of Experiments 1 and 2, which would have the maximal power. This seems legitimate as the design was the same and the only difference was the slight difference in where the boundary location was.

Combined analysis—As indicated in Table 3, the difference between the identical and TL condition was not close to significant on any measure ($t < 1$). For first fixation duration, there was a 16 ms preview effect, $t = 4.03$, $pMCMC < .001$, and an 18 ms overall transposed letter effect, $t = 4.15$, $pMCMC < .001$, and the interaction of this effect with target word condition was not close to significant, $t < 1$; the transposed letter effect was 18, 21, and 15 ms for the novel prefixed word, lexicalized prefixed word, and non-prefixed word conditions, respectively. For gaze duration, there was a 43 ms preview effect, $t = 4.95$, $pMCMC < .001$, and a 45 ms transposed letter effect, $t = 5.27$, $pMCMC < .001$. The transposed letter effect was 66, 33, and 37 ms for the novel prefixed word, lexicalized prefixed word, and non-prefixed word conditions, respectively. Even though the effect appeared to be larger for the novel prefixed words, the interaction of the TL effect with whether the target word was lexical was not significant, $t = 1.60$, $pMCMC = .11$. In addition, these analyses make clear that, for the early measures, there was no difference between the non-prefixed words and the lexicalized prefixed words in the size of the transposed letter effect.

With the increased power of combining the two experiments, most of the effects were significant in the later measures as well. For go-past time, there was a 13 ms overall preview effect, $t = 2.71$, $pMCMC < .01$, and a 31 ms transposed letter effect, $t = 3.02$, $pMCMC < .01$. For total time, the 12 ms preview effect was not significant, $pMCMC > .05$, but the 30 ms overall transposed letter effect was, $t = 2.47$, $pMCMC < .01$.

We also examined the combined data of Experiments 1 and 2 to determine whether the bigram properties of the stimuli affected the results. Among other things, one would assume that both the TL and SL stimuli had lower bigram frequencies than the word that they were constructed from. This is indeed true, as the average bigram frequency for the target words (both type and token frequency) was significantly higher than the TL adaptations for all three classes of stimuli (novel prefixed, lexical prefixed, and non-prefixed), $t_s < 4$, $p_s < .001$. Thus, the fact that gaze durations in the TL preview condition were no different from those in the identical preview condition in Experiments 1 and 2 was in spite of this large difference in bigram frequency and suggests that position-sensitive bigram coding plays little or no part in the encoding of the parafoveal preview.

The difference in bigram frequency between the target words and the SL variants was as straightforward for both classes of prefixed words, $t_s < 6$, $p_s < .001$, but was somewhat less so for the non-prefixed words, $t(35) = 3.225$, $p < .005$, for type bigram frequency, and $t(35) = 1.873$, $p < .10$, for token bigram frequency. This suggests that there might have been a slight confound such that the SL stimuli in the non-prefixed condition were somewhat more “wordlike” than the TL stimuli and that this difference worked against finding a larger SL–TL difference in the non-prefixed condition than in the prefixed condition. However, when the differences in gaze between the TL and identical conditions for the non-prefixed target words were correlated over items with the difference in bigram frequency between the

identical and TL preview, the correlations were virtually zero ($r = -.024$ for token frequency and $+.015$ for type frequency). Thus, it seems unlikely that this slight difference in the stimuli between the non-prefixed and lexical prefixed conditions was why the SL–TL difference was no larger in former condition.

Experiment 3

Experiments 1 and 2 demonstrate that, in the timeline of visual word processing, letter position encoding in the parafovea likely occurs prior to any morphemic decomposition. This is contradictory to the results reported in the Dunabeitia et al. (2007) and Christianson et al. (2004) studies, where the transposed letter effect either diminished or disappeared when the letters crossed an affix-stem boundary. However, both of these studies used foveal primes rather than parafoveal previews to examine the transposed letter effect in polymorphemic words. Experiment 3 employed a foveal masked priming paradigm to determine whether the difference in findings was due to differences between early word identification processes in the parafovea and early word identification processes in the fovea. Thus, if the pattern of results in Experiment 3, which used the same materials as Experiments 1 and 2, is the same as in the prior two experiments, it would indicate that the difference in findings is due to differences between the languages. On the other hand, if the pattern of results in Experiment 3 is different than in Experiments 1 and 2 – with the transposed letter effect diminishing when the transposed letters cross a morpheme boundary – then that would indicate that letter position encoding is different in the fovea and parafovea.

One design feature of the experiment is worth noting. As indicated in the introduction, some of the masked priming experiments with morphemically complex words used the whole word as both prime and target whereas others used the morphemically complex word as the prime and the root morpheme as the target. Because we wanted the series of events to mirror those in Experiments 1 and 2, we decided to have the whole word be the target as well as the prime. This, however, makes the lexical decision task harder because it is hard to judge lexicality for longer polymorphemic words. This led to two decisions. First, we eliminated the novel prefixed words, as the decision about whether these are words or not is quite problematic: they have a definite meaning but just have likely not been encountered by the participant. The second was the broader decision about what to use for nonword targets in the task. We opted for using nonwords that often had stems that were not pseudowords, but had legitimate prefixes so that the lexical decision times would not be too long or variable. The possible problem with this decision is that it has the danger of trivializing the lexical decision judgments. However, as will be seen from the data, the lexical decision times were not abnormally short, so that we think that participants were processing the word targets in the task to a reasonably deep level.

Method

Participants—Fifty-four undergraduate students from the University of Massachusetts of Amherst participated in the study for extra credit in their psychology courses. They were all native speakers of English and had normal or corrected-to-normal vision. They were all naïve to the purpose of the experiment.

Apparatus and procedure—Stimulus presentation and data recording was controlled by E-Prime (Version 2.0; Psychology Software Tools, 2008) software on a PC compatible computer with a CRT monitor. Participants indicated their responses using the keyboard. When participants arrived for the experiment, they were given a written description of the experimental situation and procedure, followed by verbal instruction about the task. They were told that they would be seeing a series of letter strings presented one at a time and that

they would be required to decide as quickly and accurately as possible whether or not each string was a word. (The participants were not told of the existence of the prime stimulus.) They viewed a centered forward mask of pound signs (#s) for 500 milliseconds, followed by the prime presentation for 66 milliseconds, and the immediate appearance of the uppercased centered target word (see Figure 3), and then indicated their lexicality judgment via the keyboard. The participants were instructed to hit the “M” key with their right index finger and the “Z” key with their left index finger for ‘word’ and ‘nonword’ decisions, respectively. The experimental trials were preceded by 20 practice trials.

Materials and design—The prime conditions were (1) identical, in which the prime was the same as the target word (e.g., *miscounted/modified*); (2) transposed letter, in which the prime transposed the last letter of the prefix and the first letter of the stem (e.g., *micsounted/moidfied*); and (3) replacement letter, in which the prime replaced the last letter of the prefix and the first letter of the stem (e.g., *mizrounted/molufied*). Experiment 3 employed identical primes, to compare TL vs. SL priming to identical vs. SL priming so that these effects could be compared to the transposed letter and preview effects of Experiments 1 and 2 (Dunabeitia et al., 2007, did not have an identical prime condition).

There were a total of 72 words and 72 nonwords. The target words were the 36 lexical prefixed and 36 lexical non-prefixed conditions in Experiments 1 and 2. The novel prefixed words from Experiments 1 and 2 were not included because it is not clear whether such stimuli would be classified as ‘words’ or ‘nonwords’, and thus their inclusion could have made the lexical decision times, in general, long and quite variable. For the nonwords, 36 prefixed nonword stimuli and 36 non-prefixed nonword stimuli were created. For both nonword lists, root frequency was matched to the lexical items, and then a consonant was substituted for an internal vowel to create a nonword (e.g., *support* becomes *pmpular*, as *support* and *popular* are matched in frequency and length). The consonant change was done to ensure that the lexical decision task was not too difficult, and the root frequency matching was done to ensure that the task was not too easy. For pseudo-prefixed nonwords, the prefix was matched to the lexical targets to ensure that participants do not use prefixes as a cue for lexical legality (e.g., *misapplied* becomes *misspkled*, as *spell* and *apply* are matched in frequency and length). The words and nonwords were presented in uppercase and were preceded by primes of the previously outlined conditions in lowercase. This helps to minimize priming due to mere physical overlap between prime and target. Three lists of materials were used so that each target appears once in each list, but each time in a different priming condition (identical, transposed-letter or substitute-letter). Different groups of participants were used for each list.

Results and Discussion

Data from incorrect responses (4.6% of word trials) and the trials with response times outside of the 250–1500 ms interval (10% of the data) were excluded from the response time analysis. Items that had fewer than nine (out of a possible eighteen) observations were also excluded from the analysis (4% of the data). The mean response latencies and percentages of error are presented in Table 4. Word type (prefixed vs. non-prefixed) was a within-subject variable for the participant analysis, and a between-item variable in the item analysis, as the prefixed and non-prefixed items were not matched. In this experiment, we conducted standard participant and item analyses for two reasons. First, there was so little data loss that there is little increased power in LMM analyses. Second, because the RT distributions were quite skewed, one had to do the analysis on the log of the response time, which makes interpreting the size of effects somewhat problematic. However, we did these LMM analyses, and the results (in terms of whether effects were significant or not) were the same as the analyses presented below.

Word Data—For the word data, the *transposed letter effect* was calculated as described in Experiments 1 & 2: the difference between the substitute letter and transposed letter conditions. For Experiment 3, there is a *priming effect* as opposed to the preview effect measured in Experiments 1 & 2. This is the difference between the substitute letter and identical conditions. Here, because there was little data loss, we used a more standard analysis of contrasts.

The latency analysis revealed a 27 ms overall (averaged across word types) transposed letter effect, $t_f(53) = 2.91, p < .01, t_{\chi}(57) = 2.06, p < .05$, and a 41 ms overall priming effect, $t_f(53) = 3.64, p < .001, t_{\chi}(57) = 3.18, p < .01$. The 12 ms difference between the identical and transposed letter conditions was not significant, $t_f(53) = 1.15, p > .20, t_{\chi}(57) = 1.12, p > .20$. The differences between the SL and TL conditions were 38 ms and 17 ms for prefixed and non-prefixed words, respectively. However, the interaction of the SL-TL difference with word type was not significant, $t_f(53) = 1.09, p > .20, t_{\chi}(57) = 1.45, p > .10$.

The error data for the non-prefixed words showed better performance for targets preceded by identical (4.1%) and transposed letter (4.0%) primes than for substitute letter primes (4.6%), though not significantly so, $t < 1$. The error data was mildly suggestive of a speed-accuracy tradeoff for the transposed letter effect in prefixed words, as participants made more errors in the transposed letter condition (5.2%) than in the identical (3.7%) and substitute letter (4.3%) conditions; however, the differences were not significant, $t < 1$.

Nonword Data—Usually, the pattern of data for nonwords in masked priming data is not particularly informative because a prime that facilitates perception may also make the stimulus feel more “wordlike” and, as a result, slow the correct *nonword* response. The latency analyses showed only an advantage of targets preceded by an identical prime relative to a substitute letter prime, significant by participants, $t_f(53) = 2.37, p < .05$, but not by items, $t_2 < 1$. For the nonprefixed nonwords, the 33 ms transposed letter effect was not significant, $t < 1$. The other effects were not significant and were typically in the wrong direction. For the pseudoprefixed nonwords, the response times were longest for targets with an identical prime and quickest for targets preceded by a substitute letter prime. These effects are difficult to interpret as processing of the nonwords involves additional processing (e.g. rejection of lexicality) in addition to the processing time prior to rejection. The error data for nonwords showed that participants were significantly more accurate when targets were preceded by substitute letter primes than when preceded by transposed letter primes, $t_f(53) = 2.78, p < .01, t_{\chi}(74) = 2.25, p < .05$.

Discussion

Experiment 3 was conducted as an English replication of Dunabeitia et al. (2007). The findings, however, replicated Experiments 1 and 2 and showed a different pattern than those in Dunabeitia et al. (2007). In Experiment 3, the transposed letter effect was, if anything, greater for the prefixed words than for the non-prefixed words, whereas Dunabeitia et al. (2007) actually found an 8 ms cost for the transposed letter condition compared to the substitute letter condition with their prefixed Spanish targets. It is possible that the slightly higher error rate for the prefixed words in the TL prime condition than that in the SL prime condition was accounting for the somewhat larger transposed letter effect in the response times for prefixed targets. However, the error difference was small enough to make it extremely likely that it could explain why a transposed letter effect occurred for the prefixed words.

In contrast to Experiments 1 and 2, there was a 19 ms difference between identical primes and transposed letter primes for the prefixed targets and a 13 ms difference overall between identical and transposed letter primes overall for the word targets. Although these

differences were far from significant, they suggest that, for foveal primes, there was some cost for the letters in the foveal prime being in the wrong order². This contrasts with Experiments 1 and 2, where the small differences between the two conditions were often “in the wrong direction”. However, as with the combined analysis of Experiments 1 and 2, the difference in lexical decision time between the identical and TL conditions correlated close to zero with the difference in bigram frequency between the two primes ($-.06$ for token frequency and $.10$ for type frequency).

GENERAL DISCUSSION

There was no evidence in Experiments 1–3 that the transposed letter effect was influenced by whether the transposed letters crossed the morpheme boundary between a prefix and the root morpheme. Moreover, this lack of difference between cross-morpheme and within-morpheme conditions was not plausibly due to a lack of power, as there was a clear transposed letter effect in all conditions (e.g., about 60 ms on gaze duration in the combined analyses of Experiments 1 and 2). In addition, the lack of a difference between prefixed words and non-prefixed words extended to the novel prefixed words. The large novelty effects observed there indicated that the morphemic decomposition route was quite heavily used for them and was possibly a necessary route for comprehension of the meaning. Prior to running Experiment 3, we had thought that a possible reason for a lack of difference between the three conditions in Experiments 1 and 2 was that letter coding was less precise in the parafovea; however, the similar results in Experiment 3 using a foveal prime indicate this is not the reason why there was no reduction of the transposed letter effect when the transposed letters crossed a morpheme boundary. The present results also make it difficult to posit that units such as bigrams are involved in early encoding processes because the transposed letter primes had much lower levels of (ordered) bigram frequencies in the critical region than the identity primes. Thus, if ordered bigrams were involved in the early encoding of a word, it would be hard to explain why the preview effects for identical and TL previews in Experiments 1 and 2 were the same in spite of this large difference in bigram frequency.

This result, together with the data of Rueckl & Rimzhim (2010), indicate that there is a stage of word encoding in English in which a significant amount of information about the letters is encoded but that (a) the system is relatively tolerant of errors in letter order and (b) that whether these violations destroy morphemic units doesn't matter. (We think the Christianson et al., 2005, results indicating a morphemic influence on TL suffix effects were quite weak.) This raises the question of how such a conclusion is compatible with the results from fast priming indicating that the morphemic structure of briefly presented primes influences lexical decision time to the target word. Although these findings seem contradictory, we think there are two possible solutions to the problem. The first solution is simpler. It is that there is morphemic involvement at the early stages of processing but that frequent small units such as prefixes and suffixes (and possibly bigrams) simply allow the perceiver to be able to overwrite errors in positional coding in the stimulus. Whether such a solution would actually work and, at the same time, not lead to many errors in word encoding is an open question that is only likely to be solved by extensive modeling work.

The second solution is that the finding that morphemes extracted from the briefly presented primes influence the time to make a lexical decision doesn't necessarily mean that the morphemic decomposition of the prime is occurring an early stage of processing. Perhaps an

²One possibility for this small cost for transposed letter primes is that our prime duration (60 ms) was slightly longer than the duration standardly employed in masked priming experiments. As a result, participants may have noticed the display change on a small percentage of the trials.

analogy with older masked semantic priming experiments might make the point clear. That is, in such experiments, a prime is briefly presented such that the participant has no conscious awareness of the prime, but processing time on the target word is influenced by whether the prime and target are associates (e.g., Balota, 1983). This paradigm certainly indicates that at least some semantic properties of the briefly presented prime are extracted; however, it doesn't necessarily mean that they were extracted during the brief presentation. That is, it could easily be that the prime reaches a relatively stable state in some short-term memory system, but only after a while does its representation activate semantic memory. A similar phenomenon could be occurring in these masked priming experiments. That is, the prime could remain in some sort of buffer memory, and in the early stages of processing, letter order is not necessarily encoded veridically and morpheme extraction does not occur in this early stage. It is only later in processing – sometime after this preliminary stage is completed but before the lexical decision response is programmed, that the morphemic decomposition occurs and then influences the lexical decision time.

This argument leads to the possibility that a similar mechanism also occurs in normal reading where parafoveal information is integrated with foveal information. That is, even though it is tempting to conclude that extraction of the parafoveal information is the initial state of processing that the later foveal processing builds on, it may be that the foveal information is the primary information leading to word encoding in reading and the parafoveal information extracted is largely “supporting evidence” that speeds the word identification process. Of course, this may depend on the length and frequency of the word, as short, frequent, and predictable words are often skipped – presumably based on the information extracted solely from the parafovea. However, the words used in experiments studying morphemic decomposition effects are almost always fairly long and are relatively low in frequency, so that complete identification of the word in the parafovea is extremely unlikely.

This then brings us back to the question of whether the results found in English are unique to English or are universal across written languages. First, let's consider Spanish. Given that the morphemic structure of Spanish words is not hugely different from English, there seems to be little reason to expect a principled difference in the phenomena across the two languages. In addition, as indicated in the introduction, the pattern of results in Spanish was not easy to interpret. One problem was that there was a different pattern of TL effects depending on how far the letters were apart; there was no reduction of the effect when the transposed letters that crossed the morpheme boundary were separated by a letter, but a reduction when the two letters were adjacent. (It is hard to think of a reason for this difference in the pattern.) There was a reliable reduction of the TL effect when the transposed letters crossed the morpheme boundary for Spanish prefixed words, but this hasn't been replicated. There was also no reduction of the TL effect when the transposed letters crossed the morpheme boundary between the two morphemes of a compound word. Thus, we think the safest conclusion is that the jury is still out on whether there is a reliable reduction of TL effects in Spanish when the transposed letters cross a morpheme boundary.

There is a possibility that the processing of morphemic information is different in a very different language like Basque, in which longer words are almost always constructed from morphemic elements and thus morphemes may play a more important role in the early processing of words. There is also evidence for the very early processing of morphemes in Semitic languages like Hebrew (Velan & Frost, 2009) and Arabic (Perea, abu Mallouh, & Carreiras, in press). Thus, there may be real differences in how morphemes enter into the word identification process in different language families.

In sum, the current results indicate that letter position is not coded precisely in the first stages of word processing in English, and furthermore, that neither morphemic units nor bigram units are interacting with the letter position information. The simplest possible explanation for this, mentioned above, is that units like prefixes and suffixes (which are also often frequent word beginning and ending bigrams and trigrams) simply overwrite minor errors in position coding at early stages of encoding in English.

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Appendix A

Each target word (capitalized) in Experiments 1–2 is followed by its (a) transposed letter nonword and (b) substitute letter nonword. Only the lexical prefixed and non-prefixed stimuli were used for Experiment 3.

Novel Prefixed Items

MISCENTERED micsentered mizventered UNMYSTERIOUSLY umnysteriously
 urwysteriosuly MISCIRCLED micsicled mirzircled MISDELIVERED midselivered
 micbelivered MISPACK mipsack mirgack REHAMMERED rheammered robammered
 REFRACTURED rferactured radraptured MISTABLUATED mitsabulated mircabulated
 UNDERCHOPPED undecropped undevahopped UNDERPOLICED undepriced
 undengoliced UNTHRILLED utnhrilled umshrilled UNFIRM ufnirm umlirm UNMODERN
 umnodern urwodern REPOLLUTE rpeollute raqollute OVERMELT ovemreלט ovecnelt
 UNDEREXERCISED undeexercised undesexercised REILLUSTRATE riellustrate
 rotllustrate REANSWER raenswer rocnsver MISEVALUTE miesvaluate micovaluate
 OVERORDER oveorrderr ovesarder PRECOMBAT prceombat prasombat UNBLAMED
 ubnlamed umdlamed UNBRAVE ubnrave umdrave UNPRIMITIVE upnprimitive
 umqprimitive PREGLUED prgelued proylued UNDERMAGNIFIED undemragnified

undesnagified UNSEWED usnewed umcewed UNALIVE uanlive umclive REATTACK
raetack roctack UNBROUGHT ubnrought umdrought UNPUBLIC upnpublic umgpublic
PRESENTOR prsenior procenior MISBILL mibsill mirdill MISEDIT miesdit micodit
MISPAID mipsaid micgaid MISPRICE mipsrice mizgrice

Lexical Prefixed Items

MISAPPLIED miaspllied mircpllied UNMISTAKABLY umnistakably urwistakably
MISCOUNTED micsounted mizrouted MISDIRECTED midsirected mizbirected
MISFILE mifsile mizbile REPOLISHED rpeolished raqolished READJUSTED raedjusted
roudjusted MISCALCULATED miscalculated mivzcalculated UNDERCOOKED
undecrooked undensooked UNDERSTAFFED undesrtaffed undecataffed UNDISTURBED
udnisturbed umbisturbed UNFAIR ufnair umbair UNHAPPY uhnappy umbappy
REARRANGE raerange rocrrange OVERLOAD ovelroad ovecbod UNDERESTIMATED
undeerestimated undeczstimated REORGANIZE roerganize rucrganize REBUILD rbeuild
rofuil MISINTERPRET miisnterpret mirunterpret OVERGROW ovegrow ovesyrow
PRESCHOOL prsechool proxchool UNMARRIED umnarried urwarried UNAWARE
uanware umoware UNPLEASANT upnpleasant umqleasant PREDATED prdated prabated
UNDERNOURISHED undenrourished undecmourished UNTIED utnied umcied
UNUSUAL uunsual umosual REAPPEAR raeppear rocpear UNWANTED uwnanted
umvanted UNCERTAIN ucertain umrertain PREMATURE prmeature poceature MISFILE
mifsile micbile MISQUOTE miquote micguote MISFILED mifsiled micliled MISLEAD
milsead micbead

Lexical Non-prefixed Items

MODIFIED moidfied molufied DOUBTLESSLY duobtlessly devbtlessly SQUANDERED
squnadered sqoendered SMUGGLED sumggled snoggled BURNISHED brunished
becnished STRAIGHTENED srtaightened sclaightened DESIGNATED deisgnated
detuguated BARBEQUED brabequed bonbequed ENTERTAINING enetraining
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Appendix B

The sentences used in Experiments 1 and 2. The target words are indicated here by italics in the order: (a) novel prefixed words, (b) lexical prefixed words and (c) lexical non-prefixed words.

The journal editor *miscentered* the mathematical formula, which caused problems.

Because the student *misapplied* the mathematical equation, the answer was wrong.

Because the student *modified* the mathematical equation, the answer was wrong.

Theresa was *unmysteriously* absent from the party because of her accident.

Theresa was *unmistakably* absent from the party because of her accident.

Theresa was *doubtlessly* absent from the party because of the argument.

Susan realized that she had *miscircled* the answer on the exam.

Susan realized that she had *miscounted* the money in her wallet.

Susan realized that she had *squandered* the money in her inheritance.

Because the shipment was *misdelivered*, John had to spend all day locating it.

Because the shipment was *misdirected*, John had to spend all day locating it.

Because the shipment was *smuggled*, John had to spend all day locating it.

Barbara was careful not to *mispack* her suitcase before her big trip to Europe.

Barbara was careful not to *misfile* her report before leaving on her big trip.

Barbara was careful not to *damage* her clothing before her photo shoot.

The blacksmith *rehammered* the suit of armor for the king.

The blacksmith *repolished* the suit of armor for the king.

The blacksmith *burnished* the suit of armor for the king.

Brian's spine was *refractured* when he fell down the stairs last week.

Brian's spine was *readjusted* when he went to the chiropractor last week.

Brian's spine was *straightened* when he went to the chiropractor last week.

Kyle was worried that he had *mistabulated* his new entries in the tax form.

Kyle was worried that he had *miscalculated* his new entries in the tax form.

Kyle was worried that he had *designated* his tasks to the wrong workers.

The chef's assistant *underchopped* the onion, which made the sauce unpleasant.

The chef's assistant *undercooked* the onion, which made the sauce unpleasant.

The chef's assistant *barbequed* the onion, which made the dish memorable.

The concert was *underpoliced* which led to lots of attempted gate crashing.

The concert was *understaffed* which led to lots of attempted gate crashing.

The concert was *entertaining* which led to lots of audience participation.

I was surprised that my dog was *unthrilled* by the new toy I bought him.

I was surprised that my dog was *undisturbed* by the thunderstorm.

I was surprised that my dog was *frightened* by the friendly visitor.

Kathy thought her teacher was *unfirm* with the students who came late to class.

Kathy thought her teacher was *unfair* with students who came late to class.

Kathy thought her teacher was *lenient* with the students who came late to class.

I thought that my mom looked *unmodern* because her hair was in an elaborate bun.

I thought that my mom looked *unhappy* because her hair was cut too short.

I thought that my mom looked *youthful* because her hair was cut in a modern style.

The company was starting to *repollute* the house lots near the factory.

The company was starting to *rearrange* the house lots near the factory.

The company was starting to *appraise* the house so it could be sold.

Chris was warned not to *overmelt* the cheese when he used the toaster oven.

Chris was warned not to *overload* the tray when he used the toaster oven.

Chris was warned not to *tolerate* the bad service at the expensive restaurant.

Because Sue had *underexercised* her arm muscles, she did badly in the swim meet.

Because Sue had *underestimated* her arm muscles, she did well in the swim meet.

Because Sue had *lengthened* her daily practices, she did well in the swim meet.

Betty was asked to *reillustrate* the children's book for the second edition.

Betty was asked to *reorganize* the children's desks before the new term.

Betty was asked to *categorize* the children's books for the town library.

The mayor refused to *reanswer* the question the third time it was asked.

The mayor refused to *rebuild* the club after the third time it was vandalized.

The mayor refused to *support* the candidate after he lied in the debate.

Young doctors are more likely to *misevaluate* a patient's symptoms.

Young doctors are more likely to *misinterpret* a patient's symptoms.

Young doctors are more likely to *marginalize* a patient's symptoms.

Rising food prices led the farmer to *overorder* wheat seed for the next season.

Rising food prices led the farmer to *overgrow* wheat in the next season.

Rising food prices led the farmer to *augment* wheat production for the next season.

Most of the time, the *precombat* period features a lot of maneuvering.

Most of the time, the *preschool* period involves a lot of social development.

Most of the time, the *campaign* period features a lot of maneuvering.

The wealthy man was *unblamed* in spite of the evidence that pointed to his guilt.

The wealthy man was *unmarried* in spite of the beautiful women who pursued him.

The wealthy man was *faultless* in spite of the evidence that pointed to his guilt.

The court decided that the *unbrave* soldier was responsible for the mission's failure.

The court decided that the *unaware* soldier was responsible for the mission's failure.

The court decided that the *negligent* soldier was responsible for the mission's failure.

John was surprised by the *unprimitive* nature of the tools found in the dig.

John was surprised by the *unpleasant* nature of the responses to his lecture.

John was surprised by the *shocking* nature of the responses to the speech.

The teacher *preglued* the kids' arts and crafts materials before the lesson.

The teacher *predated* the kids' homework assignments before the lesson.

The teacher *gathered* the kids' homework assignments after the lesson.

The biological specimen was *undermagnified* so we could not see it clearly.

The biological specimen was *undernourished* so we changed its diet.

The biological specimen was *sterilized* so we could all touch it.

The manager saw all of the *unsewed* sneakers and wondered who was responsible.

The manager saw all of the *untied* sneakers and wondered who was responsible.

The manager saw all of the *packaged* sneakers and wondered who had done the job.

The ranger knew that the tree was *unalive* before he came near it.

The ranger knew that the tree was *unusual* before he came near it.

The ranger knew that the tree was *lifeless* before he came near it.

They were afraid that the enemy would *reattack* before they had time to prepare.

They were expecting the enemy to *reappear* soon, so they were prepared for the battle.

They were expecting the enemy to *evacuate* soon, so they were unprepared for the battle.

Rachel fretted about her *unbrought* gift throughout Jane's birthday party.

Rachel fretted about her *unwanted* gift throughout Jane's birthday party.

Rachel fretted about her *breakable* gift because she hadn't marked it fragile.

Tim's reply was careful as the situation was still *unpublic* and also delicate.

Tim's reply was careful as the situation was still *uncertain* and also delicate.

Tim's reply was careful as the situation was still *classified* and also delicate.

Mary and Bob didn't want their *presenior* daughter to go to the prom.

Mary and Bob didn't want their *premature* daughter to get sick.

Mary and Bob didn't want their *youngest* daughter to date yet.

Jackie was worried that her assistant would *misbill* the important client.

Jackie was worried that her assistant would *misfile* the important information.

Jackie was worried that her assistant would *irritate* the important client.

Elizabeth was careful not to *misedit* the testimony of the witness.

Elizabeth was careful not to *misquote* the testimony of the witness.

Elizabeth was careful not to *falsify* the testimony of the witness.

Jill worried she had *mispaid* an important tax assessment.

Jill worried she had *misfiled* an important tax assessment.

Jill worried she had *skipped* an important tax deadline.

The car dealer was known to *misprice* his automobiles in advertisements.

The car dealer was known to *mislead* his customers about his automobiles.

The car dealer was known to *manipulate* his pricing of his automobiles.

* |

Because the student miaspplied the mathematical equation, the exam was confusing.

| *

Because the student misapplied the mathematical equation, the exam was confusing.

Preview Conditions

Identical = misapplied

Transposed Letter = miaspplied

Replacement Letter = miorpplied

The asterisk denotes the position of the eye, and the “|” denotes the invisible boundary.

Figure 1.

Example Sentence for Experiment 1 for the Lexical Prefixed Condition

* |

Because the student *miaspplied* the mathematical equation, the exam was confusing.

| *

Because the student *miaspplied* the mathematical equation, the exam was confusing.

Preview Conditions

Identical = misapplied

Transposed Letter = miaspplied

Replacement Letter = miorpplied

The asterisk denotes the position of the eye, and the “|” denotes the invisible boundary.

Figure 2.

Sentence for Experiment 2 for the Lexical Prefixed Condition

Figure 3.
Figure Representing Masked Priming with Lexical Decision Paradigm with Prefixed
Transposed Letter Prime for Experiment 3

Table 1

LMM Means as a Function of Word Type and Preview Type for Experiment 1

	First Fixation	Gaze Duration	Go Past	Total Time
Novel Prefixed Identical	257	372	440	573
Novel Prefixed TL	258	364	447	557
Novel Prefixed SL	280	416	504	586
Lexical Prefixed Identical	253	322	359	465
Lexical Prefixed TL	236	313	346	385
Lexical Prefixed SL	270	334	366	435
Lexical Non-Prefixed Identical	240	300	335	405
Lexical Non-Prefixed TL	243	301	366	403
Lexical Non-Prefixed SL	259	350	389	420

Note. All durations are in milliseconds.

Table 2

LMM Means as a Function of Word Type and Preview Type for Experiment 2

	First Fixation	Gaze Duration	Go Past	Total Time
Novel Prefixed Identical	259	394	518	608
Novel Prefixed TL	252	392	496	580
Novel Prefixed SL	269	467	551	613
Lexical Prefixed Identical	239	331	411	464
Lexical Prefixed TL	250	329	381	425
Lexical Prefixed SL	263	371	420	472
Lexical Non-Prefixed Identical	244	298	338	366
Lexical Non-Prefixed TL	238	297	356	405
Lexical Non-Prefixed SL	254	327	373	412

Note. All durations are in milliseconds.

Table 3

LMM Means as a Function of Word Type and Preview Type for Experiments 1 & 2 Combined

	First Fixation	Gaze Duration	Go Past	Total Time
Novel Prefixed Identical	258	387	492	596
Novel Prefixed TL	254	383	480	571
Novel Prefixed SL	272	449	534	607
Lexical Prefixed Identical	244	327	393	465
Lexical Prefixed TL	245	324	369	412
Lexical Prefixed SL	266	357	401	459
Lexical Non-Prefixed Identical	242	299	337	380
Lexical Non-Prefixed TL	240	298	360	405
Lexical Non-Prefixed SL	255	335	401	415

Note. All durations are in milliseconds.

Mean lexical decision times and percent of errors (in parentheses) for the targets in Experiment 3

Table 4

	Type of Prime		Transposed Letter Effect (SL-T L)	Priming (SL-ID)
	Identical	Transposed Letter		
Word Trials				
Prefixed Pairs	789 (3.7)	808 (5.2)	846 (4.3)	57 (0.6)
Non-prefixed Pairs	770 (4.1)	777 (4.0)	794 (4.6)	24 (0.5)
Nonword Trials				
Pseudoprefixed Pairs	936 (4.9)	925 (4.3)	915 (2.8)	-21 (-2.1)
Non-prefixed Pairs	899 (8.8)	894 (10.2)	927 (3.4)	28 (-5.4)

Note. All durations are in milliseconds.