

Morphemes in their place: Evidence for position-specific identification of suffixes

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Previous research strongly suggests that morphologically complex words are recognized in terms of their constituent morphemes. A question thus arises as to how the recognition system codes for morpheme position within words, given that it needs to distinguish morphological anagrams like *overhang* and *hangover*. The present study focused specifically on whether the recognition of suffixes occurs in a position-specific fashion. Experiments 1 and 2 revealed that morphologically complex nonwords (*gasful*) are rejected more slowly than orthographic controls (*gasfil*) but that the same interference effect is not present when the morphemic constituents are reversed (*fulgas* vs. *filgas*). Experiment 3 went further in demonstrating that reversing the morphemes within words (e.g., *nesskind*) does not yield morpheme interference effects against orthographic controls (e.g., *nusskind*). These results strongly suggest that suffix identification is position specific, which imposes important constraints on the further development of models of morphological processing.

Previous research on the identification of morphologically complex words like *player* has established that such words are decomposed into their constituent morphemes (i.e., *play* + *er*) during recognition. Evidence for decomposition comes largely from the findings that (1) the time taken to recognize a morphologically complex word is partly determined by the frequency of its stem (e.g., Baayen, Dijkstra, & Schreuder, 1997; Bradley, 1980; New, Brysbaert, Segui, Ferrand, & Rastle, 2004) and (2) the recognition of stem targets is speeded by the prior brief presentation of morphologically related words (e.g., Drews & Zwitserlood, 1995; Grainger, Colé, & Segui, 1991; Rastle, Davis, Marslen-Wilson, & Tyler, 2000) more than would be expected on the basis of pure orthographic or semantic overlap.

Another well-described phenomenon used to investigate morpheme recognition is the morpheme interference effect on nonword rejection times. This effect refers to the finding that nonwords comprising existing morphemes (e.g., *shootment*) are rejected more slowly in lexical decision than are nonwords that do not have a morphological structure (e.g., *shootmant*). This result was first reported by Taft and Forster (1975), who found that nonwords composed of existing prefixes and bound stems (e.g., *dejuvenate*) were rejected more slowly than were nonwords composed of the same prefixes but nonexistent stems (e.g., *depertoire*). Caramazza, Laudanna, and Romani (1988) went on to show that Italian pseudoinflected nonwords comprising existing stems and suffixes (e.g., *cant-evi*, similar to *buyed* in English) were rejected more slowly and elicited higher error

rates than did (1) nonwords comprising stems plus a nonsuffix endings (e.g., *cant-ovi*, *buyel*), (2) nonwords comprising nonstems plus suffix endings (e.g., *canz-evi*, *biyed*), and (3) nonwords comprising nonstems plus nonsuffix endings (e.g., *canz-ovi*, *biyel*). The usual explanation for this effect is that morphemic representations are activated during the processing of morphologically structured nonwords, thus slowing rejection time (Caramazza et al., 1988). In contrast to some recent models claiming that morphological processing is a postlexical phenomenon (e.g., Giraudo & Grainger, 2001), the morpheme interference effect suggests strongly that morphemic representations are activated *prior* to the activation of orthographic lexical entries (see also Kazanina, Dukova-Zheleva, Geber, Kharlamov, & Tonciulescu, 2008; Longtin, Segui, & Hallé, 2003; Marslen-Wilson, Bozic, & Randall, 2008; Rastle, Davis, & New, 2004; Taft, 1994).

Evidence that morphologically complex words are recognized through a process of decomposition that takes place prior to the activation of orthographic lexical entries raises an important theoretical issue that has largely gone unnoticed in psycholinguistic research. Specifically, how is it that we are able to distinguish between morphologically complex stimuli comprising the same morphemes but in reversed order (e.g., *preheat* vs. *heatpre*)? This question relates to a more general issue about the code used by the word recognition system to represent morpheme position: Does this code allow morphemes to be recognized independently of their positions, or is their recognition dependent on their surrounding context? The related issue of

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letter position coding has been the subject of fairly intense study in recent years, and here the evidence favors models that assume position-invariant letter representations (for reviews, see Davis, 2006; Grainger, 2008). Intuitively, one might expect that morpheme representations should also be position invariant; otherwise, the *-ness* in *kindness* would be different from the *-ness* in *aimlessness*. However, it could be the case that the recognition of affixes is dependent on their position relative to stems (e.g., *-ness* would be recognized only if it occurred after a stem).

Some evidence pertaining to this question has been obtained in Chinese. For example, Taft, Zhu, and Peng (1999) reported slower recognition times for transposable Chinese compounds—that is, bimorphemic words whose morphemes could be transposed to form another complex word (something comparable to the English example *hangover*, which shares the same constituent morphemes as the word *overhang*). These results were interpreted in terms of interference between words sharing morphemes in different positions and were thus taken as indicating some degree of position invariance in morphological representations. However, there are several factors hampering a direct generalization of these results to other languages. Chinese uses a syllabic script, in which single characters correspond to syllables rather than phonemes; this script most likely requires a rather different functional organization of the word recognition system than in English (e.g., Taft et al., 1999). Moreover, unlike English and other Western languages, the Chinese morphological system is heavily based on compounding, with a complete absence of derivation and inflection. Thus, it is difficult to use this evidence to settle the question of whether English morphemes are represented in a position-specific or a position-invariant manner.

Nevertheless, some evidence has been obtained in English that parallels the results described by Taft et al. (1999) in Chinese. Taft (1985) reported that reversed compounds (e.g., *stooltoad*) are more difficult to reject in a lexical decision task than are ordinary compound nonwords (e.g., *tallmop*). Reversed compounds have also been shown to elicit longer rejection times than have compound nonwords, including semantically related morphemes, like *fastslow* (Shoolman & Andrews, 2003). Unfortunately, though, neither of these experiments included orthographic controls for the reversed compounds, thus making it difficult to determine whether they indicate a morphological or a purely orthographic effect (e.g., that *stooltoad* is more similar to an existing word—i.e., *toadstool*—than is *tallmop*).

In the present work, we begin to consider the issue of morpheme position coding by using the morpheme interference effect to investigate whether morphemes in the “wrong” position activate lexical representations during word recognition. Specifically, we tested whether suffixes are accessed by the word recognition system when they occur at nonword onset (e.g., *nesstrue*), thus yielding a processing disadvantage, relative to matched nonwords without a morphological structure (e.g., *nelstrue*). Experiment 1 thus comprised four conditions. The first two conditions included morphologically structured nonwords (e.g., *gasful*) and their matched orthographic controls (e.g., *gasfil*), whereas the final two conditions consisted

of these stimuli with the morphemes reversed (e.g., *fulgas* and *filgas*). If suffixes are recognized by skilled readers independently of their position, we should observe equivalent interference from the *gasful* and *fulgas* stimuli, relative to their orthographic controls. If, instead, suffix representations are position specific, suffixes should not be recognized when occurring at nonword onset; in this case, we would not expect the *fulgas* stimuli to yield an interference effect, relative to their orthographic controls.

EXPERIMENT 1

Method

Participants. Forty-seven undergraduate students at Royal Holloway, University of London, participated in the experiment; all were native speakers of English and had no history of learning disabilities and/or neurological impairment. The participants were given £5 in exchange for their time.

Materials. The experimental stimulus set comprised four groups of 64 nonwords. In the stem-plus-suffix condition, existing stems were combined with existing suffixes (e.g., *gasful*). These combinations were always syntactically legal; that is, suffixes were attached to stems belonging to the grammatical class that they normally modify (e.g., *-ful* was attached only to nouns, as in *peaceful*, or to verbs, as in *forgetful*). Nonwords in this condition were constructed by using 16 different suffixes, each of which was attached to four different stems. We did not include in the stimulus set suffixes that (1) were homographic with existing words (e.g., *-ant*), (2) were most frequently used as inflections (e.g., *-ed*), (3) often resulted in allomorphic changes of the stem (e.g., *-ion*), or (4) were one letter long (e.g., *y*). In the stem-plus-control condition, the same stems were combined with nonmorphological endings that were orthographically similar to the suffixes used in the stem-plus-suffix condition (e.g., *gasfil*). Nonmorphological endings were created by changing one letter of each of the suffixes used in the first condition; if possible (i.e., in three- and four-letter-long suffixes), the change was made in a central position, so as to make sure that the letters lying at the morphemic boundary remained the same. Items in the suffix-plus-stem condition were created by reversing the order of the two constituents of items from the stem-plus-suffix condition (e.g., *fulgas*). Likewise, items in the control-plus-stem condition were created by reversing the order of the two constituents of items from the stem-plus-control condition (e.g., *filgas*). The complete list of nonword stimuli used in Experiment 1 is provided in Appendix A.

The use of the same morphemes across conditions ensured pairwise matching for stem and suffix frequency and also ensured that the nonwords in the four conditions were matched with respect to number of letters. The suffix conditions were also matched listwise with the control conditions with respect to number of syllables (see Table 1). Because morphemes also constitute frequently occurring clusters of letters (as opposed to their nonmorphological counterparts), it was impossible to match mean log bigram frequency (MLBF) between the suffix and control conditions. However, we ensured that the difference in MLBF between the suffix and control conditions did not vary as a function of whether the suffix occurred in the initial or final position of the nonwords. We reasoned that, should a morpheme interference effect emerge only when morphemes occupy their usual positions (e.g., *gasful* vs. *gasfil*), this matching of MLBF differences across position conditions would allow us to conclude that MLBF was not sufficient to explain the observed results. Care was also taken to guarantee that the nonwords in the four conditions were matched with respect to measures of their orthographic similarity to existing words. Thus, the suffix and control conditions were closely matched with respect to number of orthographic neighbors, as well as their mean orthographic Levenshtein distance (i.e., edit distance) to the nearest word neighbor (Yarkoni, Balota, & Yap, 2008).

Since the same morphemes were used across conditions, the experimental nonwords were distributed over four different rotations,

Table 1
General Characteristics of the Stimuli Used in Experiment 1

	Stem-Plus-Suffix (e.g., <i>gasful</i>)		Stem-Plus-Control (e.g., <i>gasfil</i>)		Suffix-Plus-Stem (e.g., <i>fulgas</i>)		Control-Plus-Stem (e.g., <i>filgas</i>)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Syll	2.36	0.48	2.34	0.48	2.48	0.50	2.50	0.50
MLBF	2.41	0.34	2.25	0.38	1.75	0.43	1.71	0.45
<i>N</i>	0.19	0.62	0.03	0.18	0.03	0.18	0.03	0.18
OLD1	1.95	0.49	2.04	0.52	2.40	0.66	2.50	0.67

Note—Syll, number of syllables; MLBF, mean logarithmic bigram frequency; *N*, number of orthographic neighbors; OLD1, orthographic Levenshtein distance to the nearest word neighbor.

each of which included 16 items per condition. This design also ensured that no participant saw (1) the same stem or (2) the same suffix in the same position twice.

Sixty-four morphologically complex words, 56 simple words, and 56 simple nonwords (obtained by changing one or two letters from existing monomorphemic words) served as filler trials in this study, thus ensuring that (1) each version of the experiment had the same number of word and nonword trials and (2) the overall proportion of morphologically (pseudo)complex stimuli (.53) was not too high. Filler stimuli were comparable to the experimental items with respect to length in letters, number of syllables, MLBF, and orthographic neighborhood size (*N*).

Procedure. The participants were tested in a dimly lit room and were instructed to decide whether or not the letter strings appearing on the screen were existing English words. The participants were given eight practice trials to familiarize themselves with the task, and each experimental session began with six warm-up filler trials that were not analyzed.

The trials started with a fixation cross presented at the center of the screen for 500 msec; the uppercase target string on which the participant had to make a lexical decision immediately followed. The target string remained on the screen until the participant's response. There was a 1-sec interstimulus interval between trials.

Stimulus presentation and data recording were controlled by the DMDX software (Forster & Forster, 2003). A two-button response box was used to record lexical decisions, with the button corresponding to a *yes* response being controlled by the participant's dominant hand.

Trial presentation within lists was pseudorandomized, so that no more than eight word or nonword targets could occur in a row; this design also ensured that no more than four experimental items were presented on 15 consecutive trials.

Results

Outliers were removed according to the following procedure. Items were excluded from the analyses if they

elicited (1) an overall error rate higher than 15% or (2) an average response time (RT) more than two standard deviations higher than the overall nonword mean. Similarly, participants were excluded if (1) their overall error rate on word or nonword trials was higher than 15% or (2) their mean RT on word or nonword trials was more than two standard deviations higher than the relevant mean RT for all the participants. Finally, individual RTs that were exceptionally long (lying over the first zero of their density function, which was 1,800 msec in this experiment) were also excluded. This procedure resulted in the exclusion of 12 items, 2 participants, and seven individual data points.

The remaining data were analyzed through by-participant and by-item ANOVAs that treated *morphological structure* (stem-plus-suffix vs. stem-plus-control) and *morpheme position* (initial vs. final) as repeated factors and *rotation* (four versions) as an unrepeated factor. The ANOVA was carried out on inverse-transformed RTs so as to increase the normality of the RT distribution (Ulrich & Miller, 1994).

The mean RT and error rate for word stimuli were 677 msec and .06, respectively. The mean RTs and error rates obtained by the participants in the four nonword conditions are reported in Table 2. The ANOVA carried out on the RT data revealed an effect of morphological structure [$F_1(1,41) = 8.40, p < .01; F_2(1,57) = 6.71, p = .01$], an effect of morpheme position [$F_1(1,41) = 122.38, p < .001; F_2(1,57) = 78.33, p < .001$], and, critically, an interaction between the two factors [$F_1(1,41) = 35.47, p < .001; F_2(1,57) = 13.71, p < .001$]. This significant interaction reflects the fact that the morpheme interference effect was present when morphemes occupied their usual positions (i.e., the suffix was in the final position, as in *gasful*) [$t_1(44) = 5.81, p < .001; t_2(60) = 3.90, p < .001$] but was absent when the order of morphemes was reversed (as in *fulgas*) [$t_1(44) = -0.95, p = .34; t_2(60) = 0.81, p = .42$].

These results are perfectly mirrored in the ANOVA carried out on error rates. The main effects of both morphological structure [$F_1(1,41) = 45.75, p < .001; F_2(1,57) = 12.09, p = .001$] and morpheme position [$F_1(1,41) = 50.46, p < .001; F_2(1,57) = 48.80, p < .001$] were significant, as was the interaction between these factors [$F_1(1,41) = 35.06, p < .001; F_2(1,57) = 13.30, p = .001$]. This interaction arose from a strong morpheme interference ef-

Table 2
Response Times (RTs, in Milliseconds) and Error Rates in Experiments 1 and 2

	Stem-Plus-Suffix (e.g., <i>gasful</i>)		Stem-Plus-Control (e.g., <i>gasfil</i>)		Suffix-Plus-Stem (e.g., <i>fulgas</i>)		Control-Plus-Stem (e.g., <i>filgas</i>)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Experiment 1								
RT	782	175	724	163	667	155	675	147
Error rate	.11	.09	.03	.06	.01	.02	.01	.02
Experiment 2								
RT	732	120	686	120	639	101	638	115
Error rate	.07	.08	.02	.04	.01	.04	.01	.04

fect when the morphemes occupied their usual positions [$t_1(44) = 6.20, p < .001$; $t_2(60) = 3.39, p = .001$] and a complete lack of effect when the order of the morphemes was reversed [$t_1(44) = 0.00, p = 1$; $t_2(60) = 0.00, p = 1$].

Following a reviewer's suggestion, we performed further post hoc analyses in order to test an alternative explanation of the absence of any interference effect in the suffix-plus-stem condition. Specifically, there were a number of control-plus-stem items that began with an existing prefix or stem—namely, *mant* (which includes *man*), *enge* (which includes *en-*, as in *entrust*), *ilm* and *ilt* (which include *il-*, as in *illogical*), *ady* (which includes *ad-*, as in *adjoin*), and *ime* (which includes *im-*, as in *imprudent*). It is possible that the presence of these units at the start of the nonword could have increased the difficulty of these items, thereby washing out any interference effect that might have emerged in the suffix-plus-stem versus control-plus-stem conditions. The role played by this possible confounding factor was checked post hoc in two ways. First, two new ANOVAs were run on inverse-transformed RTs and on error rates that included, as an additional factor, the presence of an existing morpheme at the onset of the control-plus-stem items. These analyses confirmed the existence of an interaction between morphological structure and morpheme position [RT analysis, $F_2(1,59) = 7.56, p = .008$; error rate analysis, $F_2(1,59) = 10.58, p = .002$], and also showed that this effect was insensitive to the presence of an existing morpheme at the onset of the control-plus-stem items [third-level interaction; RT analysis, $F_2(1,59) = 1.74, p = .19$; error rate analysis, $F_2(1,59) = 1.19, p = .28$]. Since the possible confounding factor only affected the suffix-plus-stem and the control-plus-stem conditions, its impact on the results of Experiment 1 was also checked by dividing the stimulus set according to whether the control-plus-stem nonwords started with an existing morpheme. Analyses on the resulting subsets showed equivalent results; that is, there was no evidence of an interference effect when suffix-plus-stem and control-plus-stem items were compared, irrespective of whether the latter nonwords contained an initial morpheme [e.g., *arytrip* vs. *adytrip*; RT analysis, $t_2(22) = 0.30, p = .77$; error rate analysis, $t_2(22) = 0.64, p = .53$] or not [e.g., *fulgas* vs. *filgas*; RT analysis, $t_2(37) = 0.647, p = .52$; error rate analysis, $t_2(37) = 0.49, p = .62$].

Discussion

The results of Experiment 1 reveal that legal combinations of existing stems and existing suffixes (e.g., *gasful*) elicit longer RTs than do nonwords including the same stems and nonmorphological endings (e.g., *gasfil*). This finding demonstrates that the morpheme interference effect previously reported by Taft and Forster (1975) for pseudoprefixed English nonwords with bound stems and by Caramazza et al. (1988) for pseudoinflected Italian nonwords also generalizes to pseudosuffixed English nonwords. These results can be most immediately interpreted as reflecting the ability of the word recognition system to access morpheme representations in nonword stimuli; since *gasful* activates the representations of both *gas* and

ful, it takes longer for the system to reject it, as compared with *gasfil*, which instead activates only *gas*, but no other morphemes.

Crucially, the same effect does not emerge when suffixes are shifted to the initial position; for example, *fulgas* was no more difficult to reject than *filgas*. The difference between the morphological nonwords and their orthographic controls was comparable in the scrambled- and unscrambled-morpheme conditions for potentially relevant factors such as length, stem frequency, and mean bigram frequency. It seems reasonable to conclude, then, that derivational suffixes were not recognized at the onsets of nonwords.

However, there is an alternative explanation of the present results that warrants consideration. Specifically, a number of the suffixes used in Experiment 1 may look relatively unusual when they occur in the initial position (e.g., *itypoor*), meaning that nonwords in the suffix-initial conditions may have been less wordlike than the nonwords in the suffix-final conditions. This aspect of the stimuli may have allowed the participants to reject the former nonwords relatively rapidly, with little lexical (or morphological) processing.

Experiment 2 was designed to address this possibility. We replicated Experiment 1, using a new set of filler words that were selected to be just as orthographically unusual as the suffix-initial nonwords. We reasoned that the inclusion of such fillers would prevent the participants in Experiment 2 from rejecting suffix-initial nonwords purely on the basis of their low orthographic plausibility as existing words (since such a strategy would also lead to very high rejection rates for the filler word stimuli).

EXPERIMENT 2

In Experiment 2, we tested the same four experimental conditions as those included in Experiment 1 (e.g., stimulus quadruples like *gumful*, *gumfil*, *fulgum*, and *filgum*), using the same set of stimuli. However, the filler words included in the previous experiment were replaced with a different set of words that were selected to be relatively orthographically unusual (e.g., *hyena*, *sphinx*, *euphoria*). Specifically, these filler words were of very low bigram frequency, and their mean orthographic neighborhood size was 0. If the absence of interference for suffix-plus-stem nonwords in Experiment 1 was due to the fact that suffixes occurring in the initial position did not automatically activate suffix representations, a similar pattern of results should be obtained in Experiment 2.

Method

Participants. Thirty-eight participants from the same population as that in Experiment 1 volunteered for this experiment. None of the participants had been included in Experiment 1.

Materials and Procedure. The stimulus materials used in this experiment were identical to those used in Experiment 1, except that the monomorphemic filler words used in that experiment were replaced by a new set of monomorphemic words (see Appendix B). The new fillers were comparable to those used in Experiment 1 with respect to length and number of syllables but were much lower with respect to orthographic wordlikeness measures such as MLBF and orthographic neighborhood size (MLBF, 1.87 ± 0.37 ; $N, 0.09 \pm 0.29$), so that they were now matched on these variables with stimuli

in the suffix-initial nonword condition (see Table 1). This matching ensured that orthographic wordlikeness could not be used as a reliable basis for participants' lexical decisions.

Results

Outliers were excluded from further analyses, following the same procedure as that used in Experiment 1, resulting in the exclusion of four items, 5 participants, and five individual data points (those that were higher than 1,800 msec).

The mean RT and error rate for word stimuli were 681 msec and .08, respectively; importantly, the participants did not experience particular problems with the orthographically implausible words (their mean RT on these stimuli was 694 msec, and their mean error rate was .10). By-participant and by-item analyses on the nonword data were conducted in the same way as in Experiment 1; mean RTs and error rates in the different experimental conditions are reported in Table 2. The RT analysis showed exactly the same pattern of results as in Experiment 1. There were significant main effects of morphological structure [$F_1(1,29) = 14.52, p = .001$; $F_2(1,59) = 7.19, p = .01$] and morpheme position [$F_1(1,29) = 94.73, p < .001$; $F_2(1,59) = 62.60, p < .001$] and an interaction between these two factors [$F_1(1,29) = 12.27, p < .005$; $F_2(1,59) = 8.93, p < .005$]. This interaction reflected a significant morpheme interference effect when suffixes occupied the final position [$t_1(32) = 6.15, p < .001$; $t_2(62) = 3.09, p < .005$] but no morpheme interference effect when the suffixes occupied the initial position [$t_1(32) = 0.02, p = .92$; $t_2(62) = 0.24, p = .81$].

The analysis of errors also revealed main effects of morphological structure [$F_1(1,29) = 10.45, p = .003$; $F_2(1,59) = 3.61, p = .06$] and morpheme position [$F_1(1,29) = 16.26, p < .001$; $F_2(1,59) = 24.01, p < .001$], and an interaction between these two factors [$F_1(1,29) = 8.63, p < .01$; $F_2(1,59) = 5.14, p < .05$]. Once again, the interaction reflected a significant morpheme interference effect when suffixes occupied the final position [$t_1(32) = 3.39, p < .005$; $t_2(62) = 2.30, p = .02$], but no morpheme interference effect when suffixes occupied the initial position [$t_1(32) = 0.63, p = .53$; $t_2(62) = -0.43, p = .67$].¹

Discussion

The results of Experiment 2 perfectly replicated those obtained in Experiment 1. Pseudoderived nonwords made up of an existing stem followed by an existing suffix (e.g., *gumful*) were rejected more slowly than nonwords that included the same stems and nonmorphological endings (e.g., *gumfil*). This interference effect was not observed when the same morphemes appeared in reversed order: Nonwords like *fulgum* and *filgum* elicited equivalent rejection times. As was noted earlier, the absence of any morpheme interference effect for suffix-initial nonwords in Experiment 1 could have conceivably been attributed to the orthographic atypicality of these nonwords (such that it was possible to classify these nonwords without engaging in morphological/lexical processing). However, the results of the present experiment allow us to reject this explanation. If the participants had classified stimuli

purely on the basis of their orthographic structure, they would have misclassified the filler words like *apocalypse*. The data showed no indication that the participants were following such a strategy. Having ruled out the possibility that nonwords like *fulgum* and *filgum* were rejected solely on the basis of their infrequent orthographic appearance, these results clearly suggest that suffix representations are not accessed by the word recognition system when they occur at the beginning of a letter string—that is, in a position that they never occupy in existing words.

One attempt to rescue the theoretical possibility of position-invariant suffix recognition might be to argue that nonword interference effects in the lexical decision task reflect the activation, not of morphemic representations, but of lexical representations, and that suffix-initial nonwords are simply not very effective at activating these representations. Suffix representations in the word recognition system may be activated and coded for position whenever suffixes occur within letter strings (irrespective of their position), but suffixes that are coded as occupying the initial position are not very effective at activating lexical representations, because there are no words that begin with suffixes. For example, a nonword like *nesslong* might weakly activate the lexical representations for *goodness*, *greatness*, or *baldness*, but the nonword *longness* will activate these same representations far more strongly because *-ness* occupies the same position and, therefore, provides a closer match to these words. Perhaps, then, if a more sensitive test of morpheme activation were available, it might be determined that suffix representations are partially activated by suffix-initial nonwords. The aim of Experiment 3 was to test this account by increasing the sensitivity with which morpheme interference effects might be detected.

EXPERIMENT 3

The final experiment we report was designed to provide one more opportunity to observe evidence for the activation of suffix representations in suffix-initial stimuli, in an experimental situation that optimized the opportunity for detecting morpheme interference effects. To do this, we examined responses to suffix-initial nonwords like *nesskind* that were formed by transposing the morphemes in existing suffixed words (i.e., *kindness*). If the morphemic representations for both *ness* and *kind* are partially activated, it seems plausible that their conjoint activation could result in the activation of the word representation for *kindness*, resulting in relatively slow and error-prone rejections of the nonword *nesskind*.

As we have reported in the introduction, there is already some evidence that nonwords formed by transposing morphemes are particularly hard to reject. Both Taft (1985) and Shoolman and Andrews (2003) reported data on the difficulty of rejecting compounds with transposed constituents (e.g., *walkjay*, *berryblack*), although these experiments did not include orthographic control conditions of the sort that we have used. It is also important to note that compounds include free morphemes, which are not directly comparable to suffixes, since the same free morpheme can occur in either a word-initial (e.g., *overload*) or

a word-final (e.g., *hangover*) position. Nevertheless, these data suggest that the activation of morphemic constituents can, in turn, activate lexical representations even when the morphemes occupy the incorrect position. Thus, if the suffix representation of *ness* is even partly activated when it occurs in word-initial position, it seems reasonable to expect that *nesskind* will result in activation of the lexical representation for *kindness* (in much the same way that *judge* can result in the activation of the lexical representation for *judge*; e.g., Perea & Lupker, 2003). This activation should then lead to rejection latencies longer than those for orthographic controls like *nusskind*.

Of course, a difference in response latencies between nonwords like *nesskind* and *nusskind* could be attributed to pure orthographic similarity, given that *nesskind* is an anagram of *kindness*, whereas *nusskind* is not. To test for this possibility, we included two additional conditions in Experiment 3. Nonwords in these two conditions were constructed in the same fashion as for the critical transposed-morpheme (*nesskind*) and control (*nusskind*) stimuli, with the exception that the base words were monomorphemic. For example, the monomorphemic word *attitude* gave rise to the transposed-halves nonword *tudeatti* and its orthographic control *tadeatti*. Any difference between the latter two conditions would be attributed to orthographic factors. Evidence of a larger difference between *nesskind* and *nusskind* would be treated as evidence of a morphological component to the interference effect, presumably reflecting the automatic activation of suffix representations.

Method

Participants. Forty-five students participated in this experiment, drawn from the same population as in Experiments 1 and 2. None of the participants took part in either of the initial experiments.

Materials and Procedure. Experimental materials were based on 34 derived words and 34 morphologically simple words. All of the 34 derived words were made up of two morphemes (e.g., *deaf-ness*) and made use of 17 different suffixes (with 2 derived words for each suffix). The criteria for selecting particular suffixes were identical to those used in Experiment 1. The 34 simple words were matched to the derived words as closely as possible for length (complex, 8.09 ± 1.44 ; simple, 8.15 ± 0.66), logarithmic written frequency (complex, 0.84 ± 0.72 ; simple, 1.12 ± 0.51), and number of orthographic neighbors (complex, 0.32 ± 0.68 ; simple, 0.21 ± 0.48).

The morphemes within the 34 derived words were reversed (e.g., *nessdeaf*) to create the stimuli for the transposed morphemes condition. These stimuli were then altered by changing a single letter in the suffix morpheme to form matched orthographic controls (e.g., *nelsdeaf*). The stimuli for the nonmorphological conditions were constructed in the same fashion, with the only difference being that the transposed halves did not correspond to morphemes. Thus, the stimuli in the transposed halves condition were created by reversing the order of the two halves of morphologically simple words (e.g., *quarrel* became *relquar*). Matched orthographic controls were constructed by changing one letter of the initial part of the transposed halves nonwords (e.g., the control for *relquar* was *ralquar*). The stimuli are listed in Appendix C.

Table 3 summarizes the characteristics of the nonwords included in the four experimental conditions. As can be seen, transposed stimuli were matched to their orthographic controls with respect to length in letters, number of syllables, MLBF, and Levenshtein distance to their nearest word neighbor. The orthographic overlap between the transposed stimuli and their base words (e.g., between *deafness* and

Table 3
Characteristics of the Stimuli Included in Experiment 3

	TM (e.g., <i>nessdeaf</i>)		TM Control (e.g., <i>nelsdeaf</i>)		TH (e.g., <i>relquar</i>)		TH Control (e.g., <i>ralquar</i>)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Length	8.09	1.44	8.09	1.44	8.15	0.66	8.15	0.66
Syll	2.88	0.77	2.85	0.74	2.50	0.51	2.53	0.51
MLBF	1.71	0.45	1.66	0.44	1.88	0.39	1.87	0.41
OLD1	2.67	0.84	2.70	0.80	3.03	0.76	3.18	0.76
OOSpat	.50	.06	.50	.07	.49	.06	.43	.08
OObigr	.61	.09	.50	.10	.66	.07	.49	.11

Note—TM, transposed morphemes; TH, transposed halves; Syll, number of syllables; MLBF, mean log bigram frequency; OLD1, orthographic Levenshtein distance to the nearest word neighbor; OOSpat, orthographic overlap with the reversed existing word (e.g., *deafness* for *nessdeaf* and *quarrel* for *relquar*) according to the spatial coding of letter position; OObigr, orthographic overlap with the reversed existing word according to the open bigram coding of letter position.

nessdeaf, and between *quarrel* and *relquar*) was also matched according to theoretical match values derived from spatial coding (e.g., Davis & Bowers, 2006) and open-bigram coding (e.g., Grainger & Whitney, 2004) models of letter position coding. This matching was intended to allow us to detect the effects of morphological similarity above and beyond those of pure orthographic similarity.

The experimental stimuli were arranged into two different versions, so that no participant saw the same suffix (or the corresponding nonmorphological ending) twice. The same filler trials as those used in Experiment 2 were also employed here; the inclusion of low-MLBF simple words ensured again that the participants could not make correct lexical decisions purely on the basis of orthographic typicality. Due to the different number of experimental stimuli included in each rotation, as compared with Experiments 1 and 2, four simple nonwords, four simple words, and four complex words were added to the final set of filler trials, so as to keep the proportion of complex stimuli constant across experiments. Filler stimuli were comparable to the experimental items for length in letters, number of syllables, MLBF, and orthographic neighborhood size.

The procedures adopted in this experiment were identical to those used in Experiments 1 and 2.

Results

Outlying data points were excluded from further analyses, following the same procedure as that used in Experiments 1 and 2; this resulted in the exclusion of two items, 6 participants, and two individual data points (those that were higher than 1,700 msec). The remaining data were then used to build the by-item and by-participant data sets, which were analyzed as in Experiments 1 and 2. The by-participant analysis was based on a mixed-design ANOVA with morphological structure (complex vs. simple) and orthographic structure (anagrams vs. orthographic controls) as repeated factors and rotation as an unrepeated factor. The design was identical in the by-item analysis, except that morphological structure was modeled as an unrepeated factor.

The RTs and error rates obtained in the four experimental conditions are reported in Table 4. The ANOVA revealed no effect whatsoever in either RT or accuracy analyses [all *F* values were lower than 1, except for the orthographic structure *F*₁ in the accuracy analysis; *F*₁(1,43) = 1.73, *p* = .20]. Null effects also emerged in the pairwise comparisons between the transposed condi-

Table 4
Response Times (RTs, in Milliseconds) and Error Rates
Obtained by the Participants in Experiment 3 in
the Four Experimental Conditions

	TM		TM Control		TH		TH Control	
	(e.g., <i>nessdeaf</i>)		(e.g., <i>nelsdeaf</i>)		(e.g., <i>relquar</i>)		(e.g., <i>ralquar</i>)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
RT	636	102	641	113	639	107	632	118
Error rate	.04	.09	.04	.09	.05	.10	.04	.08

Note—TM, transposed morphemes; TH, transposed halves.

tions and their matched orthographic controls [all *t* values were lower than 1, except for the by-participant transposed halves vs. transposed halves control comparison in the accuracy analysis; $t_1(44) = 1.50, p = .14$]

Discussion

Experiment 3 was designed to test whether nonwords beginning with suffixes would exhibit a morpheme interference effect in the context of transposed morpheme nonwords like *nesskind*. Previous research (Shoolman & Andrews, 2003; Taft, 1985) has suggested interference effects for nonwords formed by transposing the morphemes in compound words (e.g., *droprain*). It was therefore expected that the transposed morpheme nonwords in Experiment 3 would provide an even greater opportunity for morpheme interference effects to occur than in Experiments 1 and 2. However, the results showed no evidence whatsoever of a morpheme interference effect: *nesskind* was no more difficult to reject than *nelskind*, despite the fact that *kindness* is a familiar word. Furthermore, it is implausible to attribute the absence of morpheme interference to the orthographic similarity of suffixes and their controls (e.g., *ness* and *nels*), given that both Experiments 1 and 2 showed large morpheme interference effects based on the same suffix-control comparisons, provided that the suffix occurred in word-final position (e.g., nonwords like *begness* were reliably slower than nonwords like *begnuss*, by around 40–60 msec). Clearly, genuine suffixes and one-letter-different controls are sufficiently different to drive strong morpheme interference effects. The critical factor appears to be the position of the suffix unit: Suffixes in the word-final position result in large interference effects, whereas suffixes in the word-initial position produce no interference. This pattern strongly suggests that suffix representations are automatically activated when suffixes occur in the final position but do not become even partially activated when the word recognition system is presented with suffixes occurring at the initial position.

GENERAL DISCUSSION

Previous research has established that the morphemic structure of a stimulus is analyzed *prior* to the activation of whole-word lexical entries in visual word recognition (e.g., Caramazza et al., 1988; Longtin et al., 2003; Rastle et al., 2004; Taft & Forster, 1975). This sublexical decomposition of morphologically complex words raises the important question of how morpheme position is repre-

sented within the word recognition system. If words are recognized on the basis of their constituent morphemes, *overhang* can be distinguished from *hangover* only by the order in which their morphemes appear. Similarly, accepting *dislike* as an existing word while rejecting *likedis* as a nonword is a decision that must be based on morpheme position. This problem has remained almost totally ignored in the empirical literature on morphological processing, and current theoretical approaches to modeling the recognition of morphologically complex words have nothing to say about this issue.

The present work begins to fill these gaps by investigating whether suffixes are represented in a position-specific manner. We used the well-known morpheme interference effect (e.g., Caramazza et al., 1988; Taft & Forster, 1975) as a behavioral diagnostic of the activation of suffix representations in visual word recognition. Consistent with previous research, results showed robust morpheme interference effects when morphologically structured nonwords were presented in their usual manner (e.g., *gasfil* vs. *gasfil*), implicating the activation of morphemic suffix representations. However, these morpheme interference effects were totally absent when nonwords were presented with their morphemes reversed (e.g., *fulgas* vs. *filgas*), a situation that persisted even when the morpheme-reversed stimuli constituted actual words when presented in their usual manner (e.g., *nesskind*). These data suggest that morphemic suffix representations are position specific; they cannot be activated when suffixes are presented in the word-initial position.

Our findings place important constraints on the further development of theories of morphological processing. On the one hand, it seems clear that morphemic stem representations must be position invariant; if they were not, readers would be unable to recognize the connection between novel morphemic combinations like *unheat* and existing words like *heating*. Furthermore, it would be difficult to explain morphological priming results in which stems shared by the prime and target do not occupy the same position (e.g., *review*–VIEW or *reward*–WARD; see Feldman, Barac-Cikoja, & Kostić, 2002, for relevant findings in Serbian). On the other hand, however, our data seem to demand that morphemic suffix representations (and presumably, morphemic prefix representations) must be position specific; if they were position invariant, we should have observed an interference effect for morpheme-reversed stimuli.

One possible speculation is that some form of position specificity is desirable in the representation of suffixes so as to avoid some automatic decompositions that would interfere with word identification. For example, although it may be helpful to automatically strip word endings like *er* in words like *waiter* (and such a strategy may also lead to the inappropriate segmentation of pseudosuffixed words like *brother*; e.g., Rastle et al., 2004), it would never be appropriate to strip *er* from the beginning of words like *error* or *ergo*. By extension, although the present evidence is restricted to suffixes, one might expect that prefixes can be stripped from word beginnings but not word endings (e.g., from *misplace* but not from *salamis*). It seems plausible

that the introduction of such positional constraints would enable a putative affix-stripping mechanism to operate more efficiently without unduly increasing its complexity or capacity for rapid automatic decomposition of morphologically complex words.

AUTHOR NOTE

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NOTE

1. As in Experiment 1, post hoc analyses were conducted to test whether the results varied depending on whether the control-plus-stem nonwords began with a (pseudo)morphological unit (e.g., *adytrip*) or not (e.g., *filgas*). In neither case was there any sign of an interference effect in the reversed-morpheme conditions.

APPENDIX A
Target Nonwords Used in Experiment 1

Stem-Plus-Suffix	Stem-Plus-Control	Suffix-Plus-Stem	Control-Plus-Stem
towerly	towerla	lytower	latower
mudly	mudla	lymud	lamud
nutly	nutla	lynut	lanut
jawly	jawla	lyjaw	lajaw
sheeter	sheetel	ersheet	elsheet
beerer	beerel	erbeer	elbeer
socketer	socketel	ersocket	elsocket
figer	figel	erfig	elfig
passment	passmant	mentpass	mantpass
opposement	opposemant	mentoppose	mantoppose
shootment	shootmant	mentshoot	mantshoot
addment	addmant	mentadd	mantadd
curtity	curtidy	itycurt	idycurt
dumbity	dumbidy	itydumb	idydumb
coldity	coldidy	itycold	idycold
poority	pooridy	itypoor	idypoor
heiric	heirig	icheir	igheir
habitic	habitig	ichabit	ighabit
altaric	altarig	icaltar	igaltar
aidic	aidig	icaid	igaid
begence	begenge	encebeg	engebeg
ripence	ripenge	encerip	engerip
flitence	flitenge	enceflit	engeflit
pickence	pickenge	encepick	engepick
gasful	gasfil	fulgas	filgas
gumful	gumfil	fulgum	filgum
taxful	taxfil	fultax	filtax
fanful	fanfil	fulfan	filfan
helmetous	helmetoes	oushelmet	oeshelmet
fellowous	fellowoes	ousfellow	oesfellow
boltous	boltoes	ousbolt	oesbolt
classous	classoes	ousclass	oesclass
freeness	freenels	nessfree	nelstree
trueness	truenels	nesstrue	nelstrue
longness	longnels	nesslong	nelslong
nextness	nextnels	nessnext	nelnext
meltance	meltange	ancemelt	angemelt
happenance	happenange	ancehappen	angehappen
prayance	prayange	ancepray	angepray
stirance	stirange	ancestir	angestir
inkism	inkilm	ismink	ilmink
aridism	aridilm	ismarid	ilmarid
antism	antilm	ismant	ilmant
elbowism	elbowilm	ismelbow	ilmelbow
earist	earilt	istear	iltear
illist	illilt	istill	iltill
urnist	urnilt	isturn	ilturn
elmist	elmilt	istelm	iltelm
tripary	tripady	arytrip	adytrip
bogary	bogady	arybog	adybog
lidary	lidady	arylid	adylid
bandary	bandady	aryband	adyband
rampize	rampize	izeramp	imeramp
pillize	pillize	izepill	imepill
treasonize	treasonime	izetreason	imetreason
mouthize	mouthime	izemouth	imemouth
digory	digody	orydig	odydig
baskory	baskody	orybask	odybask
flipory	flipody	oryflip	odyflip
warnory	warnody	orywarn	odywarn
witchish	witchith	ishwitch	ithwitch
angelish	angelith	ishangel	ithangel
beanish	beanith	ishbean	ithbean
wigish	wigith	ishwig	ithwig

APPENDIX B
Simple Filler Words Used in Experiment 2

Topaz; hyena; koala; sphinx; larynx; zodiac; vortex; thorax; zombie; embryo; coyote; algebra; dilemma; academy; rhubarb; episode; synonym; nirvana; paradox; jubilee; sarcasm; turmoil; pilgrim; hygiene; diploma; scenario; protocol; panorama; volcano; platypus; nicotine; appendix; skeleton; evacuate; delirium; epilogue; euphoria; synopsis; kangaroo; souvenir; anecdote; linoleum; dinosaur; crucifix; kamikaze; daffodil; dyslexia; innuendo; petroleum; barracuda; crocodile; pneumonia; gymnasium; apocalypse; eucalyptus; rhinoceros.

APPENDIX C
Target Nonwords Used in Experiment 3

TM	TM Control	TH	TH Control
lysteep	gysteeep	trethea	trothea
lymere	gymere	iffsher	effsher
erthead	urthead	turecul	tarecul
ersell	ursell	relquar	ralquar
mentbase	mirtbase	tateagi	tafeagi
mentpunish	mirtpunish	tudeatti	tadeatti
itycomplex	ibycomplex	glestrug	glastrug
ityvalid	ibyvalid	settecas	sattecas
icarab	ocarab	trastcon	tristcon
icperiod	ocperiod	sisempha	fisempha
encediffer	engediffer	cretecon	clitecon
encerefer	engerefer	thysympa	physympa
fulfaith	falfaith	loguedia	lothedia
fulcheer	falcheer	traitpor	troitpor
oushazard	oashazard	ulesched	ilesched
ousdanger	oasdanger	laumbrel	taumbrel
nessdeaf	nelsdeaf	mercecom	merpecom
nesswit	nelswit	thonmara	thunmara
anceassist	angeassist	tainfoun	tuinfoun
anceperform	angeperform	ranguaha	rangeha
ismego	irmego	quentfre	quintfre
ismalcohol	irmalcohol	tiquecri	tishecri
istart	irtart	lainchap	loonchap
istunion	irtunion	relsquir	rulsquir
arydiet	alydiet	rioncite	liancite
arycustom	alycustom	lengechal	langechal
izecitic	ifecritic	niquetech	noquetech
izereal	ifereal	teeguaran	taeguaran
ifynull	igynull	bourneigh	bairneigh
ifyfort	igyfort	susconsen	sisconsen
orydirect	otydirect	latechoco	litechoco
orytransit	otytransit	oldthresh	eldthresh
ishwarm	iphwarm	taclespec	tuclespec
ishfool	iphfool	ricanehur	rolanehur

Note—TM, transposed morpheme; TH, transposed halves.

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