MORPHEMES IN THEIR PLACE:

EVIDENCE FOR POSITION-SPECIFIC IDENTIFICATION OF SUFFIXES

Davide Crepaldi[§], Kathleen Rastle[#], & Colin J. Davis[#]

§ Department of Psychology, University of Milano-Bicocca

Department of Psychology, Royal Holloway University of London

RUNNING HEAD: SUFFIX IDENTIFICATION IS POSITION-SPECIFIC

Address for Correspondence:

Davide Crepaldi
Dipartimento di Psicologia, Università di Milano-Bicocca
Piazza dell'Ateneo Nuovo 1
20126, Milano
Italy
E-mail: davide.crepaldi1@unimib.it
Telephone: +39 (0)2 6448 3840 (direct)
Fax: +39 (0)2 6448 3706 (departmental)

Abstract

Previous research strongly suggest 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 versus 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 poses important constraints on the further development of models of morphological processing.

Keywords: visual word recognition, pre-lexical morphology, lexical decision, morpheme interference effect, orthographic 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 (a) the time taken to recognize a morphologically-complex word is partly determined by the frequency of its stem (e.g., Bradley, 1979; Baayen, Dijkstra, & Schreuder, 1997; New, Brysbaert, Segui, Ferrand, & Rastle, 2004) and (b) the recognition of stem targets is speeded by the prior brief presentation of morphologically-related words (e.g., Grainger, Colé, & Segui, 1991; Drews & Zwitserlood, 1995: 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 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 nonwords composed of the same prefixes but non-existing stems (e.g., depertoire). Caramazza, Laudanna and Romani (1988) went on to show that Italian pseudo-inflected 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 (i) nonwords comprising stems plus a non-suffix endings (e.g., cant-ovi, buyel) (ii) nonwords comprising non-stems plus suffix endings (e.g., canz-evi, biyed), and (iii) nonwords comprising non-stems plus non-suffix 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 post-lexical 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 Longtin, Segui, & Halle, 2003; Rastle, Davis, & New, 2004; Kazanina, Dukova-Zeleva, Geber, Kharlamov, & Tonciulescu, 2008; Marslen-Wilson, Bozic, & Randall, 2008; 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. hheatpre)? 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 letter position coding has been the subject of fairly intense study in recent years, and here the evidence favours 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 to 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 on transposable Chinese compounds, i.e., 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 generalisation 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 inform the question of whether English morphemes are represented in a position-specific or in 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 ordinary compound nonwords (e.g., tallmop). Reversed compounds have also been shown to elicit slower rejection times than 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 test 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 comprises four conditions. The first two conditions include morphologically-structured nonwords (e.g., gasful) and their matched orthographic controls (e.g., gasfil), while the final two conditions consist of these stimuli with morphemes reversed (e.g., fulgas and filgas). If suffixes are recognised 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 recognised 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. 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, i.e., suffixes were attached to stems belonging to the grammatical class that they normally modify (e.g., -ful was only attached 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 (i) were homographic with existing words (e.g., -ant), (ii) were most frequently used as inflections (e.g., -ed), (iii) often resulted in allomorphic changes of the stem (e.g., -ion), or (iv) were one-letter long (e.g., y). In the stem-plus-control condition, the same stems were combined with non-morphological endings that were orthographically similar to the suffixes used in the stem-plus-suffix condition (e.g., gasfil). Non-morphological endings were created by changing one letter of each of the suffixes used in the first condition; if possible (i.e., in 3- and 4-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 non-morphological 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 as to guarantee that 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 neighbours, as well as their mean orthographic Levenshtein distance (i.e., edit distance) to the nearest word neighbour (Yarkoni, Balota, & Yap, 2008).

Table 1 about here

As the same morphemes were used across conditions, the experimental nonwords were distributed over four different rotations, each of which included 16 items per condition. This design also ensured that no participant saw (i) the same stem or (ii) 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 (i) each version of the experiment had the same number of word and nonword trials, and (ii) 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 neighbourhood size (N).

Procedure

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. Participants were given 8 practice trials to familiarize themselves with the task, and each experimental session began with 6 warm-up filler trials that were not analysed.

Trials started with a fixation cross presented in the centre of the screen for 500 ms; the uppercase target string on which the subject had to make a lexical decision immediately followed. The target string remained on the screen until the participant's response. There was a one-second inter-stimulus 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 pseudo-randomized, so that no more than 8 word or non-word targets could occur in a row; this design also ensured that no more than four experimental items were presented in 15 consecutive trials.

Results

Outliers were removed according to the following procedure. Items were excluded from the analyses if they elicited (i) an overall error rate higher than 15% or (ii) an average response time more than two standard deviations higher than the overall nonword mean. Similarly, participants were excluded if (i) their overall error rate on word or nonword trials was higher than 15%, or (ii) their mean response time on word or nonword trials was more than two standard deviations higher than the relevant mean response time for all participants. Finally, individual response times (RT) that were exceptionally long (lying over the first zero of their density function, which was 1800 ms in this Experiment) were also excluded. This procedure resulted in the exclusion of 12 items, two participants, and seven individual data points.

The remaining data were analysed through by-subject 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 reaction time and error rate for word stimuli was 677 ms and .06 respectively. The mean reaction times and error rates obtained by the participants in the four nonword conditions are reported in Table 2(a). The ANOVA carried out on response time 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] = -.95; $p = .34$; t_2 [60] = .81; $p = .42$).

These results are perfectly mirrored in the ANOVA carried out on error rates. Both the main effects of 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 arises from a strong morpheme interference effect when 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 morphemes was reversed (t_1 [44] = .00; $p = 1$; t_2 [60] = .00; $p = 1$).

Table 2 about here

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 include man), enge (which include en-, as in entrust), ilm and ilt (which include il-, as in illogical), ady (which include ad-, as in adjoin), and ime (which include 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 vs. 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 response times 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), while also showing 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). As 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, i.e., there was no evidence of an interference effect when comparing suffix-plus-stem vs. control-plus-stem items, irrespective of whether these latter nonwords contained an initial morpheme (e.g., arytrip vs. adytrip; RT analysis: t_2 [22] = .30; p = .77; error rate analysis: t_2 [22] = .64; p = .53) or not (e.g., fulgas vs. filgas; RT analysis: t_2 [37] = .647; p = .52; error rate analysis: t_2 [37] = .49; p = .62).

Discussion

The results of Experiment 1 reveal that legal combinations of existing stems and existing suffixes (e.g., gasful) elicit longer response times than nonwords including the same stems and non-morphological endings (e.g., gasfil). This finding demonstrates that the morpheme interference effect previously reported by Taft and Forster (1975) for pseudo-prefixed English nonwords with bound stems, and by Caramazza et al. (1988) for pseudo-inflected Italian nonwords, also generalises to pseudo-suffixed 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; as gasful activates the representations of both gas and ful, it takes longer to the system to reject it as compared to 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, e.g., 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 the 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 recognised 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 word-like than the nonwords in the suffix-final conditions. This aspect of the stimuli may have allowed 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 participants in Experiment 2 from rejecting suffix-initial nonwords purely on the basis of their low orthographic plausibility as existing words (as 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 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 neighbourhood 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 initial position do 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 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 neighbourhood size (MLBF: 1.87 ± .37; N: .09 ± .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 used in Experiment 1, resulting in the exclusion of four items, five participants and five individual data-points (those that were higher than 1800 ms).

The mean reaction time and error rate for word stimuli was 681 ms and .08 respectively; importantly, the participants did not experience particular problems with the orthographically implausible words (their mean RT on these stimuli was 694 ms and their mean error rate was .10). By-subject and by-item analyses on the nonword data were conducted in the same way as for Experiment 1; mean reaction times and error rates in the different experimental conditions are reported in Table 2(b). 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 suffixes occupied the initial position (t_1 [32] = .02, p = .92; t_2 [62] = .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] = .63, p = .53; t_2 [62] = -.43, p = .67)[1].

Discussion

The results of Experiment 2 perfectly replicate those obtained in Experiment 1. Pseudo-derived nonwords made up of an existing stem followed by an existing suffix (e.g., gumful) were slower to reject than nonwords that include the same stems and non-morphological 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 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 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 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, i.e., 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. Experiment 3 aimed 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 optimised 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. Taft (1985) and Shoolman and Andrews (2003) both reported data on the difficulty of rejecting compounds with transposed constituents (e.g., walkjay, berryblack), though 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, as the same free morpheme can occur in either word-initial (e.g., overload) or word-final position (e.g., hangover). 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 jugde can result in the activation of the lexical representation for judge, e.g., Perea & Lupker, 2003). This activation should then lead to slower rejection latencies than 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 subjects took part in either of the initial experiments.

Materials and Procedure

Experimental materials were based on 34 derived words and 34 morphologically simple words. The 34 derived words were all made up of two morphemes (e.g., deaf-ness) and made use of 17 different suffixes (with two 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 ± .66), logarithmic written frequency (complex: .84 ± .72; simple: 1.12 ± .51) and number of orthographic neighbours (complex: .32 ± .68; simple: .21 ± .48).

The morphemes within the 34 derived words were reversed (e.g., nessdeaf) to create the stimuli for the transposed morphemes (TM) 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 non-morphological 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 transposed halves (TH) 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 TH nonwords (e.g., the control for relquar was ralquar). Stimuli are listed in Appendix C.

Table 3 summarises 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 neighbour. The orthographic overlap between the transposed stimuli and their base words (e.g., between deafness and 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 effects of morphological similarity above and beyond those of pure orthographic similarity.

Table 3 about here

The experimental stimuli were arranged into two different versions, so that no participant saw the same suffix (or the corresponding non-morphological ending) twice. The same filler trials used in Experiment 2 were also employed here; the inclusion of low-MLBF simple words ensured again that 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 to 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 neighbourhood 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 used in Experiments 1 and 2; this resulted in the exclusion of two items, six participants and two individual data-points (those that were higher than 1700 ms). The remaining data were then used to build the by-item and by-subject datasets, which were analysed as in Experiment 1 and 2. The by-subject 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 modelled as an unrepeated factor.

The response times and error rates obtained in the four experimental conditions are reported in Table 4. The ANOVA revealed no effect whatsoever in either reaction time or accuracy analyses (all F values were lower than 1, except for 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 conditions and their matched orthographic controls (all t values were lower than 1, except for the by-subject TH vs. TH-control comparison in the accuracy analysis; t_1 [44] = 1.50, p = .14)

Table 4 about here

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 Experiments 1 and 2 both 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 to 60 ms). 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 word-final position result in large interference effects, whereas suffixes in 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 represented within the word recognition system. If words are recognized on the basis of their constituent morphemes, then overhang can only be distinguished from hangover 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 modelling 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 behavioural 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., gasful versus 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 versus 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 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 then 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 prime and target do not occupy the same position (e.g., review-VIEW or reward-WARD; see Feldman, Bara-Cikoja, & Kostic, 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, then 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.

References

Andrews, S. (1996) Lexical retrieval and selection processes: Effects of transposed-letter confusability. Journal of Memory and Language, 35, 775-800. doi:10.1006/jmla.1996.0040

Baayen, R. H., Dijkstra, T., & Schreuder, R. (1997). Singulars and plurals in Dutch: Evidence for a parallel dual-route model. Journal of Memory and Language, 37, 94–117. doi:10.1006/jmla.1997.2509

Bradley, D. C. (1979). Lexical representation of derivational relation. In Aronoff, M. and Kean, M.L. (Eds.), Juncture. Cambridge, MA: MIT Press.

Caramazza, A., Laudanna, A., & Romani, C. (1988). Lexical access and inflectional morphology. Cognition, 28, 297-332. doi:10.1016/0010-0277(88)90017-0

Chambers, S. M. (1979). Letter and order information in lexical access. Journal of Verbal Learning and Verbal Behavior, 18, 225–241. doi:10.1016/S0022-5371(79)90136-1

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. C. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. Psychological Review, 108, 204-256. doi: 10.1037/0033-295X.108.1.204

Davis, C. J. (2006). Orthographic input coding: A review of behavioural data and current models. In S. Andrews (Ed.), From inkmarks to ideas: Current issues in lexical processing. Psychology Press.

Drews, E. & Zwitserlood, P. (1995). Morphological and orthographic similarity in visual word recognition. Journal of Experimental Psychology: Human Perception & Performance. 21, 1098-1116. doi: 10.1037/0096-1523.21.5.1098

Feldman, L.B., Bara-Cikoja, D. & Kostic, A. (2002). Semantic aspects of morphological processing: Transparency effects in Serbian. Memory & Cognition, 30(4), 629-636.

Forster, K. I. & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. Behavior Research Methods, Instruments & Computers, 35, 116-124.

Giraudo, H. & Grainger, J. (2001). Priming complex words: Evidence for supralexical representation of morphology. Psychonomic Bulletin & Review, 8, 127-131.

Grainger, J. (2008). Cracking the orthographic code: An introduction. Language and Cognitive Processes, 23, 1-35. doi: 10.1080/01690960701578013

Grainger, J., Colé, P., & Segui, J. (1991). Masked morphological priming in visual word recognition. Journal of Memory and Language, 30, 370-384. doi:10.1016/0749-596X(91)90042-I

Grainger, J. & Jacobs, A.M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. Psychological Review, 103, 518-565. doi: 10.1037/0033-295X.103.3.518

Grainger, J. & Whitney, C. (2004). Does the huamn mind raed wrods as a wlohe? Trends in Cognitive Sciences, 8, 58-59. doi:10.1016/j.tics.2003.11.006

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

Kazanina, N., Dukova-Zheleva, G., Geber, D., Kharlamov, V., & Tonciulescu, K. (2008). Decomposition into multiple morphemes during lexical access: a masked priming study of Russian nouns. Language and Cognitive Processes, 23, 800-823. doi: 10.1080/01690960701799635

Longtin, C.M., Segui, J., & Hallé, P.A. (2003). Morphological priming without morphological relationship. Language and Cognitive Processes, 18, 313-334. doi: 10.1080/01690960244000036

Lupker, S.J., Perea, M., & Davis, C. J. (in press). Transposed letter priming effects: Consonants, vowels and letter frequency. Language and Cognitive Processes.

Marslen-Wilson, W.D., Bozic, M., & Randall, B. (2008). Early decomposition in visual word recognition: Dissociating morphology, form, and meaning. Language and Cognitive Processes, 23, 394-421. doi: 10.1080/01690960701588004

McClelland, J. L. & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. Psychological Review, 88, 375–407.

New, B., Brysbaert, M., Segui, J., Ferrand, L., & Rastle, K. (2004). The processing of singular and plural nouns in French and English. Journal of Memory and Language, 51, 568-585. doi:10.1016/j.jml.2004.06.010

Perea, M., & Carreiras, M. (2008). Do orthotactics and phonology constrain the transposed-letter effect? Language and Cognitive Processes, 23, 69-92. doi: 10.1080/01690960701578146

Perea, M., & Fraga, I. (2006). Transposed-letter and laterality effects in lexical decision. Brain and Language, 97, 102-109. doi:10.1016/j.bandl.2005.08.004

Perea, M., & Lupker, S. J. (2003). Transposed-letter confusability effects in masked form priming. In S. Kinoshita and S. J. Lupker (Eds.), Masked priming: State of the art (pp. 97-120). Hove, UK: Psychology Press.

Rastle, K., Davis, M. H., Marslen-Wilson, W. D., & Tyler, L. K. (2000). Morphological and semantic effects in visual word recognition: A time course study. Language and Cognitive Processes, 15, 507-538. doi: 10.1080/01690960050119689

Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. Psychonomic Bulletin & Review, 11, 1090-1098.

Schoonbaert, S. & Grainger, J. (2004). Letter position coding in printed word perception: Effects of repeated and transposed letters. Language & Cognitive Processes, 19, 333–367. doi: 10.1080/769813932

Shoolman, N. & Andrews, S. (2003) Racehorses, reindeers and sparrows: Using masked priming to investigate morphological influences on word identification. In S. Kinoshita & S. Lupker (Eds.), Masked Priming: The State of the Art (pp. 241-278). New York: Psychology Press.

Taft, M. (1985). The decoding of words in lexical access: A review of the morphographic approach. In D. Besner, T.G.Waller, & G.E. MacKinnon (Eds.), Reading Research: Advances in Theory and Practice (pp. 83-126). New York: Academic Press.

Taft, M. (1994). Interactive-activation as a framework for understanding morphological processing. Language and Cognitive Processes, 9, 271-294.

Taft, M. & Forster, K.I. (1975). Lexical storage and retrieval of prefixed words. Journal of Verbal Learning and Verbal Behavior, 14, 638-647. doi:10.1016/S0022-5371(75)80051-X

Taft, M., Zhu, X, & Peng, D. (1999). Positional specificity of radicals in Chinese character recognition. Journal of Memory and Language, 40, 498-519. doi:10.1006/jmla.1998.2625

Ulrich, R., & Miller, J. (1994). Effects of truncation on reaction time analysis. Journal of Experimental Psychology: General, 123, 34-80. doi: 10.1037/0096-3445.123.1.34

Yarkoni, T., Balota, D., & Yap, M. (2008). Moving beyond Coltheart's N: A new measure of orthographic similarity. Psychonomic Bulletin and Review, 15, 971-979. doi: 10.3758/PBR.15.5.971

Appendixes

Appendix A. Target nonwords used in Experiment 1.

Stem-plus-suffix	Stem-plus-control	Suffix-plus-stem	Suffix-plus-control
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

Stem-plus-suffix	Stem-plus-control	Suffix-plus-stem	Suffix-plus-control
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	nelsfree
trueness	truenels	nesstrue	nelstrue

Stem-plus-suffix	Stem-plus-control	Suffix-plus-stem	Suffix-plus-control
longness	longnels	nesslong	nelslong
nextness	nextnels	nessnext	nelsnext
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

Stem-plus-suffix	Stem-plus-control	Suffix-plus-stem	Suffix-plus-control
rampize	rampime	izeramp	imeramp
pillize	pillime	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	gysteep	trethea	trothea
lymere	gymere	iffsher	effsher
erteach	urteach	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	rangueha	rangleha
ismego	irmego	quentfre	quintfre

TM	TM-control	TH	TH-control
ismalcohol	irmalcohol	tiquecri	tishecri
istart	irtart	lainchap	loonchap
istunion	irtunion	relsquir	rulsquir
arydiet	alydiet	rioncrite	liancrite
arycustom	alycustom	lengechal	langechal
izecritic	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

Author Note

The present work was carried out at the Department of Psychology, Royal Holloway University of London, where the first author was holding a post-doctoral fellowship granted by the Economic and Social Research Council, UK (PTA-026-27-1825). We gratefully acknowledge the contribution of research grants from the Leverhulme Trust (F/07 537/AB), the British Academy (SG-51566), and the ESRC (RES-000-22-3354). We would also like to thank Sebastian Loth for his assistance in the selection of the orthographically unusual filler words in Experiment 2.

Footnotes

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.

Tables

Table 1. General characteristics of the stimuli used in Experiment 1.

	Stem-plus-suffix (e.g., gasful)		Stem-plus-control (e.g., gasfil)		Suffix-plus-stem (e.g., fulgas)		Suffix-plus-control (e.g., filgas)	
	M	SD	M	SD	M	SD	M	SD
Syll	2.36	.48	2.34	.48	2.48	.50	2.50	.50
MLBF	2.41	.34	2.25	.38	1.75	.43	1.71	.45
N	.19	.62	.03	.18	.03	.18	.03	.18
OLD1	1.95	.49	2.04	.52	2.40	.66	2.50	.67

Note – Syll, number of syllables; MLBF, mean logarithmic bigram frequency; N, number of orthographic neighbours; OLD1, orthographic Levenshtein distance to the nearest word neighbour.

Table 2. Reaction times (RT, in ms) and error rates in Experiment 1 and Experiment 2.

		Stem-plus-suffix (e.g., gasful)		Stem-plus-control (e.g., gasfil)		Suffix-plus-stem (e.g., fulgas)		Suffix-plus-control (e.g., filgas)	
		M	SD	M	SD	M	SD	M	SD
(a) Exp 1	RT	782	175	724	163	667	155	675	147
	Error rate	.11	.09	.03	.06	.01	.02	.01	.02
(b) Exp 2	RT	732	120	686	120	639	101	638	115
	Error rate	.07	.08	.02	.04	.01	.04	.01	.04

Table 3. Characteristics of the stimuli included in Experiment 3.

	TM (e.g., nessdeaf)		TM-control (e.g., nelsdeaf)		TH (e.g., relquar)		TH-control (e.g., ralquar)	
	M	SD	M	SD	M	SD	M	SD
Length	8.09	1.44	8.09	1.44	8.15	.66	8.15	.66
Syll	2.88	.77	2.85	.74	2.50	.51	2.53	.51
MLBF	1.71	.45	1.66	.44	1.88	.39	1.87	.41
OLD1	2.67	.84	2.70	.80	3.03	.76	3.18	.76
OOspat	.50	.06	.50	.07	.49	.06	.43	.08
OObigr	.61	.09	.50	.10	.66	.07	.49	.11

Note – Syll, number of syllables; MLBF, mean log bigram frequency; OLD1, orthographic Levenshtein distance to the nearest word neighbour; 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.

Table 4. Reaction times (RT, in ms) and error rates obtained by the participants in Experiment 3 in the four experimental conditions.

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