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Seeing Stems Everywhere: Position-Independent Identification of Stem Morphemes

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There is broad consensus that printed complex words are identified on the basis of their constituent morphemes. This fact raises the issue of how the word identification system codes for morpheme position, hence allowing it to distinguish between words like *overhang* and *hangover*, and to recognize that *preheat* is a word, whereas *heatpre* is not. Recent data have shown that suffixes are identified as morphemes only when they occur at the end of letter strings (Crepaldi, Rastle, & Davis, 2010, "Morphemes in Their Place: Evidence for Position-Specific Identification of Suffixes," *Memory & Cognition, 38,* 312–321), which supports the general proposal that the word identification system is sensitive to morpheme positional constraints. This proposal leads to the prediction that the identification of free stems should occur in a position-independent fashion, given that free stems can occur anywhere within complex words (e.g., over*dress* and *dress*er). In Experiment 1, we show that the rejection time of transposed-constituent pseudocompounds (e.g., *moonhoney*) is longer than that of matched control nonwords (e.g., *moonbasin*), suggesting that *honey* and *moon* are identified within *moonhoney*, and that these morpheme representations activate the representation for the word *honeymoon*. In Experiments 2 and 3, we demonstrate that the masked presentation of transposed-constituent pseudocompounds (e.g., *moonhoney*) facilitates the identification of compound words (*honeymoon*). In contrast, monomorphemic control pairs do not produce a similar pattern (i.e., *rickmave* did not prime *maverick*), indicating that the effect for *moonhoney* pairs is genuinely morphological in nature. These results demonstrate that stem representations differ from affix representations in terms of their positional constraints, providing a challenge to all existing theories of morphological processing.

Keywords: visual word identification, morpheme, position coding, lexical decision, masked priming

Research over the past 30 years has demonstrated convincingly that morphologically complex words are analyzed in terms of their morphemic constituents during visual word recognition. For example, it has been shown repeatedly that the recognition of a stem target (e.g., *depart*) is facilitated by the prior masked presentation of a word that is inflectionally (e.g., *departing*; Crepaldi, Rastle, Coltheart, & Nickels, 2010) or derivationally related (e.g., *departure*; Drews & Zwitserlood, 1995) in a manner that cannot be explained by the orthographic or semantic overlap that characterizes morphological relatives (e.g., Rastle, Davis, Marslen-Wilson, & Tyler, 2000). Similarly, numerous studies have shown that the frequency of a stem (e.g., *dark*) influences the time taken to recognize a word derived from that stem (e.g., *darkness*; Bertram, Baayen, & Schreuder, 2000; New, Brysbaert, Segui, Ferrand, & Rastle, 2004). These findings have led to a broad consensus that morphologically complex words are decomposed in the visual

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word recognition process. However, they have also triggered a spirited debate as to whether morphological decomposition arises sublexically, that is, prior to the activation of whole words (e.g., Andrews & Davis, 1999; Rastle, Davis, & New, 2004; Taft & Forster, 1975) or as a consequence of whole word identification (e.g., Giraudo & Grainger, 2001). On the former account, the morphologically complex stimulus *cleaner* would activate the morphemic units {clean} and {-er}, which, in turn, would activate the word unit {cleaner}; on the latter account, the stimulus *cleaner* would directly activate its word unit, which, in turn, would activate the morphemic units {clean} and {-er}.

Because the postlexical (or, as it is sometimes referred to, *supralexical*) theory posits that morphological analysis is triggered by lexical identification, it predicts no morphological effects at all when processing nonwords because lexical identification never occurs for nonwords. Thus, for example, the letter string *tablehood* should be easily rejected as a nonword because that particular letter combination does not exist in the orthographic lexicon, and the morphemes {table} and {-hood} would never have become activated. However, it is clear that this prediction does not fit with the existing data. For example, Taft and Forster (1975) reported that pseudoprefixed nonwords such as *devive* elicit slower NO responses in a lexical decision task than nonwords composed of the same prefix plus a nonexisting stem (e.g., *defant*), suggesting that the pseudoprefixed stimuli had been morphemically decomposed. Many similar reports are available in the literature both in the inflectional domain (e.g., Caramazza, Laudanna, & Romani, 1988) and in the derivational domain (e.g., Burani, Dovetto, Thornton, & Laudanna, 1997), and there is also substantial evidence from masked priming studies for the decomposition of morphologically structured nonwords (e.g., McCormick, Rastle, & Davis, 2009; Meunier & Longtin, 2007). This evidence all favors a sublexical account of morphological decomposition in which morphologically structured stimuli are segmented into their constituents prior to the activation of whole word representations (e.g., Rastle et al., 2004).

If morphemes are identified prior to the activation of whole word representations, however, that fact raises a critical question as to how morphemes are coded for position in the recognition system. Specifically, are morphemes recognized independently of their position, or is their recognition dependent on their occurrence in a particular position? Researchers have invested great effort in recent years to understand how it is that monomorphemic words which are anagrams of one another (such as *tea*, *ate*, and *eat*) are distinguished, and yet the related problems of how we distinguish words such as *overhang* and *hangover,* or understand that *retry* is a word but that *tryre* is not, have received much less attention. Crepaldi, Rastle, and Davis (2010) have provided an initial investigation of this issue using pseudosuffixed nonwords. They demonstrated that morphologically structured nonwords like *shootment* are harder to reject in visual lexical decision than nonwords without morphological structure like *shootmant*, but that this interference effect vanishes if the stem and the suffix are shifted in position (e.g., rejection latencies for nonwords like *mentshoot* and *mantshoot* do not differ).

Crepaldi, Rastle, and Davis (2010) interpreted these findings as evidence that suffix representations are position-specific: Suffixes do not activate morphemic representations when they occur at the onset of a letter string. Although this constraint might just stem from a general sensitivity of the visual identification system to statistical regularities, they also speculated that positional constraints might be implemented in the word identification system in order to avoid automatic decomposition in some cases in which it would clearly interfere with recognition. For example, identifying the suffix {-ment} in words like *mental* or *mention* should not occur because it would never lead to the retrieval of the correct meaning. This tentative speculation leads to the more general suggestion that the word identification system should be sensitive to the positional constraints of *all* types of morphemes (e.g., prefixes, bound stems). However, given that free stems appear in different positions within complex words (e.g., *over* appears in initial position in *overwork*, but in final position in *stopover*; *cat* appears in initial position in *catfish*, but in final position in *wildcat*), a different prediction should be made about the position coding of free stems, namely, that they are position independent.

Suggestive evidence consistent with this prediction was provided by Taft (1985), who reported that transposed compounds (e.g., *doorback*) elicit slower NO responses in a lexical decision task than pseudocompounds (e.g., *pipemeal*). This finding suggests not only that the morphemes *door* and *back* are identified within *doorback* (presumably, the same happens to *pipe* and *meal* in *pipemeal*), but also that they are able to activate the lexical representation of *backdoor* even if they lie in the wrong position. Unfortunately, though, this experiment was reported only anecdotally in Taft (1985), and several details about the experiment—such as the matching between experimental and control stimuli, the types of nonword trials used, the number of subjects tested—were not available to the reader.

Data examining rejection times for transposed-constituent pseudocompounds were also provided by Shoolman and Andrews (2003). They carried out a masked priming experiment with the aim of investigating constituent priming in compounds (e.g., *neck-NECKLACE* vs. *lace-NECKLACE* vs. *straw-NECKLACE*). Targets in the nonword trial set included simple nonwords (e.g., *skensile*), pseudocompounds involving unrelated words (e.g., *toadwife*), pseudocompounds involving associated words (e.g., *startstop*), and transposed-constituent pseudocompounds (e.g., *moonhoney*). Considering only the rejection times for these nonwords in the unrelated-prime condition, latencies for transposed-constituent pseudocompounds were quite similar to those for associate-word and unrelated-word pseudocompounds, thus providing contrasting evidence to that reported by Taft (1985). Although these results should be regarded cautiously because the nonword trials were foil trials in this experiment (and therefore the relevant stimuli might not be perfectly comparable in terms of constituent frequency, length, orthographic neighborhood size, etc.), they are surely suggestive that presenting *doorback* to skilled readers does not drive activation to the lexical representation for *backdoor*.

A more carefully controlled experiment on the role of position in the identification of written morphemes was carried out in Chinese by Taft, Zhu, and Peng (1999). In a lexical decision experiment explicitly designed to assess this issue, Taft et al. found out that transposable Chinese compounds—bimorphemic words whose morphemes could be shifted in position to form another word—were classified more slowly than nontransposable compounds. These results were taken as evidence that morphemes activate word units even when they lie in the “wrong” position. Using English examples, the presentation of the letter string *over-*

hang would activate the lexical representation for *hangover* (just as the presentation of *doorback* appeared to activate the lexical representation for *backdoor* in Taft [1985]), which would create competition and, hence, delay the processing of *overhang*. Unfortunately, it is very difficult to generalize these findings to English (or to any other Indo-European language for that matter) given the completely different morphological structures of the two languages. More generally, it is very unlikely that the word identification system has the same architecture in alphabetic and ideographic scripts (e.g., Bi, Han, Weekes, & Shu, 2007; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Taft et al., 1999), given the different constraints that the visual stimuli place on the perceptual system and the radically different nature of the orthography-to-phonology mapping (which is likely to shape the architecture of the word identification system; e.g., Rastle & Brysbaert, 2006).

Other data that are relevant for understanding the nature of position coding of free morphemes were obtained in Basque by Duñabeitia, Laka, Perea, and Carreiras (2009). In a series of masked priming experiments, these authors showed facilitation among compounds that shared a constituent in different positions. For example, *sumendi* (meaning volcano) – composed of *su* (fire) and *mendi* (mountain) – primed *mendikate* (meaning mountain range) – composed of *mendi* (mountain) and *kate* (chain), relative to an unrelated baseline such as *laguntza* (meaning help). This cross-positional priming was, however, numerically smaller than standard constituent priming (i.e., when primes and targets share a constituent in the *same* position; e.g., *lan-postu-LAN-ORDU*, workplace-working hour), and the critical comparison (*sumendi-MENDIKATE* vs. *lagunzta-MENDIKATE*) was only marginally significant by items. Further, as with the data obtained in Chinese by Taft et al. (1999), it is not clear whether this evidence can be generalized to Indo-European languages: Although Basque has the same alphabetic writing system as English, it is an agglutinative, non-Indo-European language with very peculiar typological characteristics and a very rich compounding system (comparable to Finnish; e.g., Duñabeitia, Perea, & Carreiras, 2007).

The experiments described in this paper were designed to assess the positional constraints that apply to the identification of English free morphemes. In Experiment 1, these constraints were assessed in a lexical decision task where the critical comparison was between transposed compounds (e.g., *applepine*) and control, morphologically structured nonwords where either constituent was substituted by a matched, unrelated word (e.g., *baconpine*). If free morpheme identification occurs in a position-independent fashion and the morpheme position coding system allows for some flexibility, we would expect *applepine* to activate the lexical representation for *pineapple*. The result would be slower rejection times for *applepine* than for *baconpine*, where the combination of the morphemes {bacon} and {pine} should not drive any lexical representation close to the identification threshold.

Experiment 1

Method

Participants. Forty-eight students from Royal Holloway, University of London took part in the study. They were all native speakers of English, they had no history of neurological impairments and/or learning disabilities, and they were paid £5 in exchange for their time.

Materials. The experimental nonwords were 48 transposed-constituent pseudocompounds (e.g., *applepine*, *boxchatter*). These were formed from 12 opaque-opaque (*OO*) compounds where neither the left nor the right component contribute to the meaning of the whole compound (e.g., *honeymoon*), 12 transparent-opaque (*TO*) compounds where the left, but not the right, component contributes to the meaning of the whole compound (e.g., *staircase*), 12 opaque-transparent (*OT*) compounds where the right, but not the left, component contributes to the meaning of the whole compound (e.g., *crowbar*), and 12 transparent-transparent (*TT*) compounds where both the left and the right component contribute to the meaning of the whole compound (e.g., *snowball*). The general features of the base compounds are reported in Table 1. Figures were computed through the N-Watch application (Davis, 2005). Each of these 48 transposed-constituent pseudocompounds was paired with a control nonword formed by changing one of the components in the original stimulus. This alteration was carried out equally on the right (e.g., *moonhoney* becomes *moonbasin*) and on the left (e.g., *boxchatter* becomes *fatchatter*) within each of the four semantic transparency groups. We also took care in matching the bigram frequency pattern over the morphemic boundary, so that experimental and control nonwords were comparable in the extent to which they could be parsed. The depth of the bigram

Table 1
Lexical, Orthographic, and Phonological Characteristics of the Base Compounds Used to Create the Critical Nonwords in Experiment 1

	OO		OT		TO		TT	
Variable	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Letters	8.25	1.43	8.67	1.08	8.58	.89	8.67	1.23
Log WF	1.16	.77	.92	.93	.91	.73	.94	.88
Log SF	.19	.31	.09	.24	.13	.17	.26	.48
Syll	2.33	1.14	2.25	1.14	2.00	1.24	2.08	1.03
Phon	6.83	3.10	6.67	3.26	6.42	3.57	6.33	3.18
N	.17	.39	.00	.00	.00	.00	.08	.29
MLBF	1.96	.43	1.90	.40	1.77	.20	1.77	.42

Note. Log WF = log-transformed written frequency; Log SF = log-transformed spoken frequency; Syll = number of syllables; Phon = number of phonemes; N = number of orthographic neighbours; MLBF = mean log bigram frequency.

trough over the morphemic boundary was operationalized as follows:

$$\mathrm{BTD} = \left|\log(BF_a) - \log(BF_b)\right| + \left|\log(BF_c) - \log(BF_b)\right|$$

where BF_a is the frequency of the bigram immediately preceding the boundary, BF_b is the frequency of the bigram straddling the boundary, and BF_c is the frequency of the bigram immediately after the boundary.[1] This index is close to zero when the bigram frequency pattern over the boundary is flat, and it grows with the depth of the trough. Bigram trough depth (BTD) means and standard deviations for the critical and control nonwords were 2.76 ± 2.19 and 3.28 ± 2.34, respectively. The complete list of the experimental and control nonwords used in this experiment is provided in Appendix A.

The mismatching components in the transposed-constituent pseudocompounds and their corresponding control nonwords were matched pair wise for length in letters (4.15 ± .77 in both conditions), log written frequency (1.60 ± .58 for the transposed-constituent pseudocompound vs. 1.58 ± .60 for their control nonwords), log spoken frequency (1.26 ± .66 vs. 1.19 ± .77), number of orthographic neighbors (*N*; 8.79 ± 5.23 vs. 8.98 ± 5.15), morphological family size (28.75 ± 25.16 vs. 17.90 ± 20.54), and strength of the semantic association with the shared component (*moon* and *chatter* in the examples above) as measured through the Latent Semantic Analysis (.14 ± .10 vs. .12 ± .10; Landauer & Dumais, 1997). Moreover, transposed-constituent pseudocompounds were matched list wise to their control nonwords for length in syllables, number of orthographic neighbors (*N*), mean orthographic Levenshtein distance to the 20 closest neighbors (OLD20; Yarkoni, Balota, & Yap, 2008), and mean log bigram frequency (*MLBF*; see Table 2). The list wise matching was also applied within transparency conditions.

Because transposed-constituent pseudocompounds and their controls shared a morpheme, they were distributed over two rotations, so that no participant saw the same morphemic constituent twice. Forty-eight compound words, 48 simple words, and 48 simple nonwords (e.g., *schidute*) served as filler trials in this experiment, thus ensuring that both the proportion of morphologically complex stimuli and the proportion of YES responses was .50 in both rotations. Filler stimuli were comparable to the experimental stimuli with respect to length in letters (8.18 ± 1.04 vs. 8.54 ± 1.15, respectively) and number of syllables (2.40 ± .60 vs. 2.17 ± .38).

Table 2
Lexical, Orthographic, and Phonological Characteristics of the Target Nonwords Used in Experiment 1

	Transposed-constituent pseudocompounds (e.g., *moonhoney*)		Control nonwords (e.g., *moonbasin*)	
Variable	Mean	*SD*	Mean	*SD*
Syll	2.19	.39	2.15	.36
N	.02	.14	.00	.00
OLD 20	3.79	.69	3.74	.64
MLBF	1.83	.42	1.87	.47

Note. Syll = number of syllables; *N* = number of orthographic neighbours; OLD20 = mean orthographic Levenshtein distance to the 20 closest neighbours; MLBF = mean log bigram frequency.

Procedure. The experimental sessions took place in a dimly lit room, and they were preceded by eight practice trials. Participants were instructed to decide whether or not the letter strings appearing on the screen were existing English words. The experimental session began with six warm-up filler trials that were not analyzed.

Each trial began with a fixation cross presented in the center of the screen for 500 ms, which was immediately followed by the uppercase target string to which the subjects had to make a lexical decision. There was no time limit for the subjects to give a response, and trials were separated by a 1-s interstimulus interval.

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. The design also ensured that no more than four experimental items were presented in 16 consecutive trials.

Statistical analysis. Individual subjects or pairs of items were excluded from the analyses if their overall error rate was at least 2.5 standard deviations higher than the relevant mean. With respect to exclusion of items, it was sufficient that one member of any pair met the exclusion criterion for the pair to be excluded. These procedures resulted in the exclusion of one subject and two pairs of items (*doortrap-soontrap* and *plantegg-plantpot*). The remaining data were inversed transformed in order to make the distribution of the dependent variable more Gaussian-like. Data were analyzed using by-subjects and by-items analyses of variance (ANOVA) that considered morphological structure (transposed-constituent pseudocompounds vs. control nonwords) and semantic transparency (*OO* vs. *OT* vs. *TO* vs. *TT*) as factors.[2] These analyses were performed using the statistical software R (R Development Core Team, 2007), freely available online at http://www.R-project.org.

Results

The mean reaction time (RT) and error rate for word stimuli were 724 ms and .13, respectively. The mean RTs and error rates in the critical nonword conditions are reported in Table 3. The analysis conducted on RTs revealed a significant effect of morphological structure ($F_1[1, 46] = 6.43$, $p = .01$; $F_2[1, 42] = 6.44$, $p = .01$), as transposed-constituent pseudocompounds (e.g., *applepine*) were rejected more slowly than control nonwords (e.g., *baconpine*). The main effect of semantic transparency was marginal ($F_1[3, 138] = 11.25$, $p < .001$; $F_2[3, 42] = 2.20$, $p = .10$), whereas the interaction between morphological structure and semantic transparency was far from significance ($F_1[3, 138] = .57$,

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[1] All frequency and neighbourhood density values are taken from the SubtLex database (Brysbaert & New, 2009), or calculated based on this database.

[2] Because the standard function for running ANOVAs in R works with Type I (sequential) sums of squares, we ran all analyses several times, one for each possible order of the covariates. Only those effects that turned out to be significant in all ANOVAs were reported as being significant.

Table 3
Mean Response Times and Error Rates in Experiment 1

Variable	TT	TO	OT	OO	Overall
RTs					
Transposed-constituent pseudocompounds	945	898	864	906	903
Control nonwords	904	866	833	865	867
Difference	41	32	31	41	36
Error rates					
Transposed-constituent pseudocompounds	.15	.13	.09	.08	.11
Control nonwords	.06	.07	.06	.09	.07
Difference	.09	.06	.03	−.01	.04

Note. TT = transposed-constituent pseudocompounds in which both constituents are related to the meaning of the compound; TO = transposed-constituent pseudocompounds in which the left-hand, but not the right-hand, constituent is related to the compound meaning; OT = transposed-constituent pseudocompounds in which the right-hand, but not the left-hand, constituent is related to the compound meaning; OO = transposed-constituent pseudocompounds in which neither constituent is related to the compound meaning.

p = .63; F_2[3, 42] = .04, p = .99), indicating that the effect of morphological structure was similar across all semantic transparency conditions.[3] The accuracy analyses revealed a significant main effect of morphological structure (F_1[1, 46] = 8.85, p = .004; F_2[1, 42] = 6.23, p = .02), no effect of semantic transparency (F_1[3, 138] = 1.65, p = .18; F_2[3, 42] = .81, p = .50), and no interaction between morphological structure and semantic transparency (F_1[3, 138] = 3.78, p = .01; F_2[3, 42] = 1.94, p = .14).

Discussion

The results of Experiment 1 demonstrate that transposed-constituent pseudocompounds (e.g., *applepine*) are more difficult to reject than morphologically structured nonwords whose constituents do not form an existing word (e.g., *baconpine*). Because the two sets of nonwords in our experiment were matched carefully on a number of factors both at the constituent and at the whole stimulus level, this difference seems unequivocally due to the fact that the morphemes in the transposed-constituent pseudocompounds, if shifted in position, form an existing compound word. These results substantiate and give a more solid experimental basis to similar suggestive evidence described by Taft (1985). They also support findings described by Taft, Zhu, and Peng (1999) in Chinese and by Duñabeitia et al. (2009) in Basque, two languages that have a completely different morphological structure than English and most other Western languages. Our results also go beyond these earlier reports in suggesting that the morpheme interference effect is not sensitive to the semantic transparency of the original compound. Therefore, the most likely conclusion is that the morpheme interference effect should be interpreted as arising at the orthographic level of analysis.

Our interpretation of these results is that the identification of the morphemes *apple* and *pine* in *applepine* activates the lexical representation for the existing word *pineapple*, thus making it difficult for the word identification system to reject the letter string as a nonword. A similar difficulty does not seem to arise when participants are presented with *baconpine*. Although we have no direct experimental evidence on this issue, it is reasonable to assume that the system identifies *bacon* and *pine* as existing morphemes; if this were not the case, it would be difficult to explain the slower latencies associated with transposed-constituent pseudocompounds like *applepine*. However, in the case of *baconpine*, the conjoint activation of the *bacon* and *straw* constituents does not significantly activate any lexical representation. As a result, it is relatively easier for the system to reject these stimuli as nonwords.

This interpretation of our results requires the assumption that free morphemes are coded flexibly, although, ultimately, accurately for their position. The recognition system must have coded *apple* as occurring before *pine*; otherwise it would have accepted *applepine* as the existing word *pineapple*, which is clearly not the case. At the same time, however, the fact that *apple* was identified as occurring in first position did not prevent the word identification system from activating the lexical representation for *pineapple*, in which the morpheme *apple* occurs in second position. This result could never occur in a system in which morpheme identification is position-specific, and the identity and position of morphemes are bound together in a way that creates two different and unrelated representations for *apple* (*apple1* and *apple2*; see Coltheart et al., 2001, and Perry, Ziegler, & Zorzi, 2010, for a similar assumption in the domain of letter position coding). It appears that, at some point in processing, the recognition system must have contacted a representation for *apple* that is not fully position-specific, thus revealing the connection between *applepine* and *pineapple*. This mechanism is most likely what permits the skilled reader to appreciate the relationship between, for example, *handpick* and *pickpocket* (or, in the domain of derived words, between *preheat* and *heating*), based on the fact that the *pick* in *handpick* is the same *pick* as in *pickpocket*, even if they occupy different positions in the words.

Before offering such a strong conclusion, however, we felt it necessary to address some issues concerning the results of Experiment 1. First, because the critical stimuli were overtly presented to the participants, we cannot exclude the possibility that strategic factors might have influenced the results. Related to that, participants may have also been slow in rejecting transposed-constituents pseudocompounds because they attributed a possible meaning to these nonwords

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[3] In an additional analysis, we assessed whether changing the left vs. the right component had any impact on rejection times. It turned out not to be the case (Morphological Structure × Constituent Position: F_1[1, 46] = .22, p = .64; F_2[1, 88] = .15, p = .70).

(e.g., it is perhaps possible to imagine what a *dogsheep* might be), more than what they did to their matched controls (it is less easy to give a possible semantic content to *dogpaint*). Second, the core result is based on nonword rejection times, and it has been suggested several times in the past that the cognitive processes leading to a NO response might differ from those that are responsible for a YES response in lexical decision (e.g., Grainger & Jacobs, 1996). Finally, we cannot rule out completely the possibility that *applepine* is difficult to reject because it is orthographically similar to the existing word *pineapple* (as opposed to an account based on the recognition of the morphemic units in *applepine*). This possibility is unlikely given that our transposed-constituent pseudocompounds were long enough to make them quite different from their corresponding compounds according to at least some theories of orthographic coding (e.g., Davis, 2010), an argument bolstered by the fact that Crepaldi, Rastle, and Davis (2010) demonstrated that shifted-halves monomorphemic nonwords (e.g., *relquar*) and their orthographic controls (e.g., *ralquar*) show equivalent rejection latencies. Nonetheless, we felt that more direct evidence would be desirable.

Experiment 2 was a masked priming experiment designed to address these issues. This experiment compared priming elicited by reversed compound primes on the identification of their corresponding compounds (e.g., *fireback-BACKFIRE*) with priming elicited by shifted-halves nonwords on the identification of their corresponding monomorphemic words (e.g., *rickmave-MAVERICK*). The masked priming paradigm keeps the critical manipulation outside the participants' awareness, thus avoiding strategic effects and excluding a semantic interpretation of the results of Experiment 1. Furthermore, because the critical comparisons all involve word identification times, this design ensures that the cognitive processes being investigated are those directly responsible for word recognition, rather than nonword rejection. Finally, this design permits us to rule out any possible orthographic similarity interpretation of the priming effect through the comparison between the morphological and the monomorphemic condition. If *fireback* primes *backfire* because *fire* and *back* are identified as morphemes and coded flexibly for their position, we should observe significantly more facilitation in the former than in the latter condition. If, otherwise, the effect is primarily driven by the orthographic similarity between primes and targets, we should obtain a similar pattern of results in the fireback-BACKFIRE and *rickmave-MAVERICK* conditions.

Experiment 2

Method

Participants. Twenty-four students at the University of Western Ontario participated in this experiment; they were all native speakers of English, and they had no history of learning disabilities or neurological impairments. Participants took part in the experiment either in partial fulfillment of the requirements of a university course or for a small cash payment.

Materials. Forty-eight simple words and 48 compounds were selected as targets for this experiment. They were all eight letters in length, and they were matched as closely as possible for log written and spoken frequency, number of syllables, number of phonemes, *N*, *OLD20*, and *MLBF* (see Table 4). Each target word was paired with two different nonword primes: In the related condition, the primes were obtained by shifting the two halves of the target words (e.g., *roidaste* was the related prime for *asteroid*, *sitecamp* was the related prime for *campsite*); in the unrelated condition the primes were randomly generated letter strings that had no letter in common with the targets (e.g., *qpgxlzbk* was the unrelated prime for *asteroid*, *jlvkxbwu* was the unrelated prime for *campsite*). Because all the target compounds were made up of two four-letter constituents, the related primes in the morphologically complex condition were transposed-constituent pseudocompounds comparable to the target nonwords used in Experiment 1 (*workcase* for *casework*, *fishgold* for *goldfish*, etc.). Random letter strings were used as unrelated primes in an attempt to increase the probability of getting priming in the nonmorphological condition, thus ensuring that any additional priming effect for the transposed-constituent pseudocompounds was genuinely morphological in nature. The complete list of the stimuli in Experiment 2 is given in Appendix B.

Table 4
Lexical, Orthographic, and Phonological Characteristics of the Target Items Used in Experiment 2

	Compound targets		Simple targets	
Variable	Mean	*SD*	Mean	*SD*
Log WF	.97	.92	1.74	.75
Log SF	.43	1.11	1.10	1.44
Syll	2.13	.33	2.65	.63
Phon	6.67	.69	7.00	.79
N	.00	.00	.06	.24
OLD20	3.28	.38	3.22	.43
MLBF	2.03	.33	2.27	.31
BTD	1.69	1.05	.83	.63

Note. Log WF = log-transformed written frequency; Log SF = log-transformed spoken frequency; Syll = number of syllables; Phon = number of phonemes; *N* = number of orthographic neighbours; OLD20 = mean orthographic Levenshtein distance to the 20 closest neighbours; MLBF = mean log bigram frequency; BTD = bigram trough depth.

Trials were distributed over two rotations so that each target was presented once in each list, either with a related or an unrelated prime. Each list was presented to half the participants. This design ensured that each participant saw each target word only once, and was exposed to both the related and the unrelated conditions, thus allowing a repeated-measures design that maximizes the statistical power of the analyses.

Ninety-six nonwords were selected as targets for the nonword trials. They were all pronounceable, they were eight letters in length, and they were free of illegal bigrams/trigrams. Half of them were paired with shifted-halves related primes, in much the same way as was done for the related word targets (e.g., *rterdesa* was the prime for *desarter*). The remaining 48 nonword targets were paired with unrelated strings of letters similar to those used in the unrelated word trials (e.g., *jlvkxbwu* was the prime for *mahodany*). This design ensured that the sets of word and nonword trials were similar and that the overall proportion of YES responses in each rotation was .50.

Procedure. The experimental sessions took place in a dimly lit room, and they were preceded by eight practice trials. The instructions to the participants were identical to those in the previous experiment, and no mention was made about the presence of a prime. Trials started with a fixation cross presented in the center of the screen for 550 ms, which was immediately followed by the prime presented in lowercase for 55 ms. The prime was followed immediately by an uppercase target string to which the subjects had to make a lexical decision. Subjects were given 3 s to provide a response, after which the target disappeared from the screen, and the next trial began. All other aspects about stimulus presentation and data recording were identical to Experiment 1.

Statistical analysis. The data trimming procedure was carried out as in Experiment 1, and it resulted in the exclusion of one subject and four targets (*flamenco*, *plethora*, *shrapnel*, and *minstrel*). The independent variables of interest were morphological structure (simple vs. compound words) and relatedness (related vs. unrelated primes), hence, the analysis was a 2 × 2 ANOVA. Because there was no evidence in Experiment 1 to suggest that transposed-constituent pseudocompounds activated their base words on the basis of semantic information, the semantic transparency of morphemic constituents was not considered in this experiment.

Results

Mean RTs and error rates are shown in Table 5. The RT analyses revealed a main effect of morphological structure (F_1[1,22] = 5.62, p = .03; F_2[1, 90] = 4.05, p = .05) and, more importantly, a significant interaction between morphological structure and relatedness (F_1[1, 22] = 10.38, p = .004; F_2[1, 90] = 7.60, p = .007). The nature of the interaction was further investigated through planned comparisons, which revealed the presence of a priming effect for compound targets (t_1[22] = 2.60, p = .008; t_2[47] = 2.43, p = .009), but not for simple targets (t_1[22] = .63, p = .73; t_2[43] = 1.45, p = .93). The accuracy analysis revealed a main effect of morphological structure (F_1[1, 22] = 7.63, p = .01; F_2[1, 90] = 4.42, p = .04), but no interaction between this factor and relatedness (F_1[1, 22] = .36, p = .55; F_2[1, 90] = .37, p = .54). Therefore, no post hoc analysis was carried out on the error data.

Discussion

The results of Experiment 2 show that transposed-constituent pseudocompounds prime their corresponding compound words more than would be expected solely on the basis of their orthographic similarity. This pattern confirms our interpretation of the results of Experiment 1, that is, that free stems are identified in pseudocompounds, and they are coded flexibly for their position so that the presentation of *sickhome* to the word identification system results in some activation of the lexical representation for *homesick*. Experiment 2 also extends the conclusions derived from Experiment 1 because it capitalized on the masked priming paradigm, which means that our results: (a) are not due to strategic effects, (b) are genuinely related to the mechanisms that are responsible for word identification, and (c) should be interpreted as arising at the orthographic level of analysis.

Table 5
Mean Response Times and Error Rates Obtained in Experiment 2

Variable	Transposed-constituent pseudocompounds	Shifted-halves monomorphemic nonwords
RTs		
Related primes	728	789
Unrelated primes	766	774
Priming effect	−38	+15
Error rates		
Related primes	.04	.09
Unrelated primes	.05	.09
Priming effect	−.01	.00

There are, however, some potential alternative explanations for the results of Experiment 2. One is based on the difference between the primes for the two target types. Reversed compounds were made up of two existing words, whereas the primes for the monomorphemic targets were not. It is possible, therefore, that the primes for the reversed compounds might have driven some activation in the lexical system that, even without resulting in any specific activation for the corresponding compound, might have biased the system toward a YES response. In other words, on the assumption that the lexical system responds YES in lexical decision on the basis of its overall activation (e.g., Coltheart et al., 2001; Davis, 2010; Grainger & Jacobs, 1996), *moonhoney* might speed up YES responses on any following word by activating the lexical nodes for their constituents (*moon* and *honey*), with no need of assuming activation in the representation for *honeymoon*.

There are two facts that argue against this hypothesis, however. First, in Experiment 1, reversed compounds were compared with control nonwords also made up of existing words (e.g., *moonhoney* vs. *moonbasin*); if the critical effect was exclusively driven by the mechanism outlined above, we would have observed equivalent rejection times for the two types of stimuli, which was not the case. It is true that the task and paradigm are different in Experiment 2; but, if anything, the circumstances of the masked priming technique actually makes this alternative account less viable than it would have been in Experiment 1 (because primes are shown for a few milliseconds, outside the participants' awareness). Second, if facilitation by transposed-constituent pseudocompounds was primarily determined by the fact that primes include two existing words, then that facilitation should be proportional to their (summed) frequency. However, there is no sign of such a correlation in the data (Pearson's r equals −.10 between priming effect and the log-transformed frequency of the first constituent, −.02 between priming effect and the log-transformed frequency of the second constituent, and −.09 between priming effect and the sum of the log-transformed frequencies of the two constituents).

There were also some differences in the nature of the two types of targets, which potentially could have caused the difference observed in Experiment 2. Because of the intrinsic features of monomorphemic and compound words in English, and because of several constraints imposed on our stimuli in Experiment 2, matching across conditions was not completely satisfactory for some variables. For example, simple target words were more frequent than their compound counterparts by around one standard deviation (see Kinoshita, 2006, for possible effects of target frequency on masked priming). Simple targets also included more syllables than compound targets, and they were higher in MLBF (again by around one standard deviation). Finally, compound targets showed their typical bigram trough pattern around the morphemic boundary (Rastle et al., 2004; Seidenberg, 1987). To illustrate with an example, the bigrams *am* and *wo* in *teamwork*—those immediately before and after the morphemic boundary—are higher in frequency than *mw*—the bigram lying on the morphemic boundary. This cue might have helped our participants to break down compounds into their constituents, thus aiding priming (the same bigram trough pattern was obviously absent in the monomorphemic targets).

In an attempt to show that the interaction between relatedness and morphological structure described above was not due to these covarying variables, we reanalyzed Experiment 2 data using mixed-effect models, which permit us to take into account several covariates, while at the same time maintaining adequate statistical power. We modeled log-transformed target frequency, number of syllables, BTD, MLBF, the covariates, and morphological structure and relatedness (the effects of interest) as fixed effects. Provided that they contributed significantly to the model goodness of fit (as assessed through a log-likelihood χ^2 test), we included into the model: (a) the main effects of the covariates, (b) the main effects of the variables of interest and their interaction, and (c) the third-level interactions between each covariate and the two variables of interest. BTD was operationalized as in Experiment 1. Random intercepts for participants and targets were also included into the model, which was fitted to inverse-transformed response times so as to make the distribution of the dependent variable more Gaussian-like. Once the final model was determined, we refitted it after excluding those data-points whose standardized residuals were higher than 2.5 (Baayen, 2008), thus ensuring that our effects were not driven by a few, overly influential outliers. Significance values were calculated through *F* tests (Bates, 2005) or Markov-Chain Monte Carlo simulations (Baayen, Davidson, & Bates, 2008). Error rates were not analyzed because no interaction between relatedness and morphological structure emerged in the ANOVA-based analyses. The code for this analysis is available from the first author on request.

The mixed-effects model revealed a significant effect of target frequency ($F[1, 1934] = 7.52$, $p = .006$), morphological structure ($F[1, 1934] = 22.79$, $p < .001$), relatedness ($F[1, 1934] = 15.08$, $p < .001$), and, more importantly, a significant interaction between morphological structure and relatedness ($F[1, 1934] = 18.02$, $p < .001$), that was not affected by any of the covariates. The nature of the interaction was clearly illustrated by the model parameter referring to related primes in the compound condition; this parameter was negative ($\beta = -.096$) and highly significant ($p < .001$), indicating that response times were shorter in this condition than in any other. This conclusion was confirmed by refitting the same mixed-effects model separately for the compound and the monomorphemic targets (by analogy to what is usually done in post hoc tests under the standard approach): A significant effect of relatedness emerged in the compound condition, $F(1, 1022) = 35.45$, $p < .001$, but not in the monomorphemic condition, $F(1, 903) = .19$, $p = .66$, thus indicating priming by transposed-constituent pseudocompounds, but not by transposed-halves monomorphemic words.

The results of the mixed-effect model analysis suggest that the data obtained in Experiment 2 were not a by-product of any target-specific covariate, nor were they due to the bigram trough pattern that typically characterizes compounds over the morphemic boundary. These considerations strengthen our conclusion that free stems are identified without positional constraints, and they are coded flexibly for their position within words.

Experiment 3

One additional factor by which compound and monomorphemic targets could not be matched in Experiment 2 is phonological structure. All compound words included two four-letter constituents so that the halves were reversed to create primes following a syllable boundary (e.g., *campsite-sitecamp*, *goldfish-fishgold*, *forecast-castfore*). Because we were interested in controlling orthographic factors in Experiment 2, we also broke down monomorphemic targets in two four-letter chunks. However, monomorphemic targets were not all made up of two four-letter syllables, and so primes were not necessarily created based on a syllable boundary (e.g., *contrast-rastcont*, *flamingo-ingoflam, dialogue-oguedial*). As a result, for several monomorphemic items, the two halves changed their pronunciation when transposed (e.g., *hantmerc* from *merchant*, *hasepurc* from *purchase*).

In order to rule out the possibility that this factor was responsible for the results of Experiment 2, we ran a new experiment with exactly the same design and procedures, but this time using targets of varying length so that we were able to match pair wise monomorphemic and compound targets for syllabic structure (e.g., *segment-sunrise*, *charter-handbag*, *syndrome-pinpoint*). This move also ensured that phonological changes only emerged in a few primes and were evenly distributed across the monomorphemic and compound conditions. We took advantage of this attempt to replicate the results of Experiment 2 to improve our materials in one additional way, namely, that there were no duplicate constituent morphemes in the experimental set (e.g., we avoided using both *campfire* and *campsite* as targets).

Method

Participants. Forty-three students at the University of Western Ontario participated in this experiment; they were all native speakers of English, and they had no history of learning disabilities or neurological impairments. Participants took part in the experiment for a small cash payment.

Materials, procedure, and statistical analysis. Thirty-eight simple words and 38 compound words were used as targets for this experiment. They were matched as closely as possible for length in letters, log frequency (both written and spoken), number of syllables, number of phonemes, *N, OLD20*, *MLBF*, and bigram trough depth (see Table 6). In the related condition, each target was paired with a nonword prime created by transposing the two syllables of the target (e.g., *fireback* from *backfire*, *droncaul* from *cauldron*), which in the compound condition coincided with the two constituent morphemes. This procedure resulted in related primes that were matched pair wise across conditions for number of letter, number of syllables and orthographic neighborhood size, and list wise for number of phonemes (6.39 ± 1.00 for the monomorphemic primes vs. 5.89 ± 1.01 for the transposed-constituent pseudocompounds), MLBF (2.02 ± .30 vs. 1.97 ± .32), orthographic overlap with the target (.47 ± .05 vs. .46 ± .06), and ease of parsability (BTD: 2.11 ± 1.89 vs. 2.27 ± 2.02). In the unrelated condition, target words were paired with random strings of letters (e.g., *znmhvxwg* was the control prime for *backfire*, *zxvghfpm* was the control prime for *cauldron*). The complete list of the stimuli used in Experiment 3 is given in Appendix C.

Table 6
Lexical, Orthographic, and Phonological Characteristics of the Target Items Used in Experiment 3

	Compound targets		Simple targets	
Variable	Mean	*SD*	Mean	*SD*
Log WF	1.71	.58	2.27	.59
Log SF	.47	.56	.85	.58
Syll	2.00	.00	2.00	.00
Phon	5.89	1.01	6.39	1.00
N	.03	.16	.53	1.08
OLD20	3.05	.34	2.68	.60
MLBF	2.06	.29	2.53	.36
BTD	2.34	1.47	1.71	1.43

Note. Log WF = log-transformed written frequency; Log SF = log-transformed spoken frequency; Syll = number of syllables; Phon = number of phonemes; N = number of orthographic neighbours; OLD20 = mean orthographic Levenshtein distance to the 20 closest neighbours; MLBF = mean log bigram frequency; BTD = bigram trough depth.

In all other respects, the materials, the experimental design, the trial procedure, and the statistical analysis were identical to those in Experiment 2.

Results

Data trimming led to the exclusion of one participant and five targets (*shrapnel*, *minstrel*, *hedgerow*, *syndrome*, and *wedlock*). Mean RTs and error rates are shown in Table 7.

The RT analyses revealed a marginally significant effect of relatedness ($F_1[1, 41] = 2.71$, $p = .11$; $F_2[1, 69] = 4.78$, $p = .03$) and, more importantly, a significant interaction between morphological structure and relatedness ($F_1[1, 41] = 7.80$, $p = .008$; $F_2[1, 69] = 6.58$, $p = .01$). This interaction was investigated through post hoc analyses, which revealed a significant effect of relatedness in the compound condition ($t_1[41] = 3.07$, $p = .003$; $t_2[35] = 3.49$, $p = .001$), but not in the monomorphemic condition ($t_1[41] = .31$, $p = .76$; $t_2[34] = .61$, $p = .54$).

Discussion

The results of Experiment 3 confirm that transposed-constituent pseudocompounds prime their corresponding compound words more than could be expected on the basis of their orthographic similarity, even after controlling for the syllabic structure of stimuli. These data are evidence that reversed compound priming is genuinely morphological in nature, thus providing support to the idea that free morphemes are identified in a position-independent manner.

General Discussion

Research over the past three decades (e.g., Grainger, Colé, & Segui, 1991; Rastle et al., 2004; Taft & Forster, 1976) has resulted in a strong consensus that the recognition of printed words is based at least in part on the analysis of their morphemic constituents. However, one barrier to proposing a theory of morphological processing is that we know little about how morpheme position is coded in visual word recognition. The findings described in this article provide the first direct evidence that English free stems are coded flexibly for their position, so that the presentation of a reversed compound such as *moonhoney* activates the lexical representation of its corresponding word (in this case, *honeymoon*).

Our findings strongly support the idea of a special role for morphology in lexical productivity. One of the necessary prerequisites for capturing the relationship between words like *unclean* and *cleaner* is to understand that the component *clean* in the first word is the same as the component *clean* in the second word, in spite of the fact that they occur in different positions in the two words. Our ability to appreciate this fact requires the representation of *clean* to be position independent, that is, for *unclean* and *cleaner* to contact the same morphological representation at some point in processing. Position independence is also a key characteristic in allowing readers to interpret morphologically structured pseudowords in a perfectly coherent fashion. Skilled readers are able to determine plausible interpretations of a novel word like *untweeting*, precisely because they are able to recognize the known stem *tweet* despite the fact that they may never have encountered it in the middle of a word before. The position independence of free morphemes is, therefore, at the heart of morphological productivity.

Although the idea that stems are represented in a position-independent fashion is supported by both a priori considerations and the results of the present experiments, it does not follow that stem position is unimportant. Indeed, stem position must be encoded in order to distinguish words like *overhang* and *hangover*. The issues that are confronted when considering the coding of stem position are quite similar to those faced by researchers studying the related problem of letter position coding. Research in that domain indicates flexibility in letter position coding sufficient to tolerate some letter transpositions (e.g., *jugde* activates the lexical representation of *judge*; Perea & Lupker, 2003; Schoonbaert & Grainger, 2004). At the same time, position coding must be sufficiently specific to permit readers to distinguish words like *clam* and *calm*.

Two of the best-known letter coding schemes that allow this combination of flexibility and relative precision are open-bigram coding (e.g., Grainger & van Heuven, 2003; Whitney, 2001) and spatial coding (Davis, 1999, 2010). In the former coding scheme, words are represented as a set of ordered letter pairs; so, *calm* would be coded by the bigram set {*ca*, *cl*, *cm*, *al*, *am*, *lm*}. Assuming the prior representation of just 676 (i.e., 26 × 26) open bigrams, it is possible to encode any English letter string. In the spatial coding scheme, words are represented via activity in position-independent letter representations (e.g., the same node for the letter *A* is contacted when the input is the word *apt*, *tap*, or *pea*). The specific ordering of the letters is encoded dynamically by the pattern of activity across these position-independent letter units (e.g., the first letter is assigned

Table 7
Mean Response Times and Error Rates Obtained in Experiment 3

Variable	Transposed-constituent pseudocompounds	Shifted-halves monomorphemic nonwords
RTs		
Related primes	710	713
Unrelated primes	745	709
Priming effect	−30	+4
Error rates		
Related primes	.05	.06
Unrelated primes	.06	.05
Priming effect	−.01	.01

a temporary position code of 1, the second letter is assigned a temporary position code of 2, and so on).

In principle, either of the above schemes could be generalized to encode the position of stem morphemes. However, the direct generalization of an open bigram scheme, whereby compound words are represented by a unique ordered pair of morphemes, seems rather implausible. For example, if a reader knows 10,000 stem morphemes, using open bigrams to encode stem position would necessitate 100 million open bigram units, with the vast majority of these (e.g., {*cat*, *umbrella*}, {*shoe*, *fountain*}) never playing any role in word identification. One option would be to suggest that the relevant open bigrams only come to be represented as a consequence of experience with specific morpheme combinations, for example, there is no {*honey*, *moon*} open bigram prior to learning the word *honeymoon*. However, this proposal then raises the question of how order would be represented for novel morpheme combinations. Furthermore, the inherent directionality of open bigram representations poses a problem for explaining the present results because, under this scheme, the {*honey*, *moon*} open bigram should not be activated by the input *moonhoney*.

By contrast, as Davis (1999) noted, the spatial coding scheme generalizes to the situation of encoding morphemes quite readily. In order to encode the word *honeymoon*, a temporary position code of 1 would be assigned to the stem representation for *honey*, and a temporary position code of 2 would be assigned to the stem representation for *moon*. Given the input *moonhoney*, exactly the same stem representations would be activated as for the word *honeymoon*, but with a slightly different spatial pattern (i.e., a code of 1 for *moon* and a code of 2 for *honey*). As a consequence, some activation of the compound representation *honeymoon* is to be expected (the situation is somewhat analogous to transposed letter similarity effects). Another important aspect of the spatial coding model that differentiates it from other computational models (Coltheart et al., 2001; Grainger & van Heuven, 2003; Perry et al., 2010) is the absence of bottom-up inhibition from letters (or bigrams) to incompatible words. Accordingly, the *h* in *honeymoon* (or *moonhoney*) excites the lexical representation of the stem *honey* without inhibiting the representation of the stem *moon*. That is, a familiar stem can be identified even when it is presented in conjunction with another stem or affix. This property is critical for achieving segmentation-through-recognition, whereby morphological decomposition is achieved via recognition of the internal constituents (e.g., Andrews & Davis, 1999).

The theoretical relevance of the results reported in this article is best appreciated when they are considered together with the data described by Crepaldi, Rastle, and Davis (2010). The current findings support the generalization proposed in that article, namely, that the word identification system is sensitive to morpheme positional distribution. Morpheme representations are position independent when they code for morphemes that can appear in different positions within complex words (free stems—the present data), but they are position-specific when they code for morphemes that can appear only in specific positions (affixes: Crepaldi, Rastle, and Davis' [2010] data). The notion that affixes and stems might be treated differently in word recognition is not new: The seminal affix-stripping theory (e.g., Taft, 1981, 1994; Taft & Forster, 1975, 1976) proposed that affixes are identified and removed, leaving the remaining stems to serve as entry keys to the lexicon. The present results, combined with those of Crepaldi, Rastle, and Davis (2010), extend affix-stripping theory by demonstrating not only that affixes and stems sub serve different goals during printed word identification (as shown by Taft and colleagues), but also that they feature different forms of representation (their position is coded differently), and they undergo different kinds of processing (suffixes are identified only at the end of letter strings, whereas stems are identified wherever they appear).

The existence of two radically different types of morphemic representations in the word identification system—one that is sensitive to context (affix) and one that is not (free stems)—calls for substantial modifications to all of the most recent models of morphological processing, regardless of whether they are localist (e.g., Taft, 2004) or employ parallel distributed processing (e.g., Plaut & Gonnerman, 2000), and regardless of whether they feature two parallel routes (letters-to-morphemes-to-words and letters-to-words; e.g., Diependaele, Sandra, & Grainger, 2009; Grainger & Ziegler, 2011) or only one (letters-to-morphemes-to-words; Crepaldi, Rastle, Coltheart, & Nickels, 2010; Rastle & Davis, 2008). None of these theories assume any difference in the cognitive processes that apply to stems and affixes. Because no positional constraints are in place to differentiate between these two types of morphemes, these theories would all seem to predict, for example, that the system identifies *ment* in *mentshoot*, contrary to what is shown in Crepaldi, Rastle, and Davis (2010). It might seem that the issue of morpheme position coding is less salient in dual-route models, because letter position coding along the whole-word route would suffice to distinguish between, for example, *overhang* and *hangover*. However, dual-route models do involve a decompositional route, and therefore, they cannot dispense with specifying how exactly such a route operates, which includes addressing questions about whether the suffix *ment* is identified within *mentshoot* as it is within *shootment*, and whether *moon* in *moonhoney* contributes activation to the lexical representation for *honeymoon*.

Finally, our data also shed new light on the nature of automatic morphological decomposition in visual word recognition (e.g., Davis & Rastle, 2010; Longtin, Segui, & Hallé, 2003; Marslen-Wilson, Bozic, & Randall, 2008; Rastle et al., 2004; Rastle & Davis, 2008). Indeed, the results reported here (and in Crepaldi, Rastle, and Davis, 2010) suggest that one factor that may facilitate the rapidity of morpho-orthographic segmentation is its apparent sensitivity to position. That is, the parser may be able to segment morphemes very rapidly because it "knows" where they can occur.

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Appendix A

Prime and Target Stimuli Used in Experiment 1

Reversed compound	Control nonword	Group	Constituent changed
moonhoney	moonbasin	OO	right
stringham	stringtoe	OO	right
busterblock	busterpride	OO	right
bookpocket	bookfellow	OO	right
tailcock	tailmaze	OO	right
bughum	bugcop	OO	right
potjack	hutjack	OO	left
linedead	showdead	OO	left
applepine	baconpine	OO	left
fallwind	sandwind	OO	left
boxsoap	liesoap	OO	left
washhog	bushhog	OO	left
heartsweet	heartstale	TO	right
marenight	marewater	TO	right
casestair	caselodge	TO	right
sportspoil	sportglobe	TO	right
sharkcard	sharkvast	TO	right
waveheat	waverole	TO	right
boxchatter	fatchatter	TO	left
ballodd	warmodd	TO	left
headwar	homewar	TO	left
nutdough	dotdough	TO	left
birdjail	fueljail	TO	left
hornshoe	lungshoe	TO	left
childgod	childbed	OT	right
wheatbuck	wheatduck	OT	right
barcrow	baroath	OT	right
boarddash	boarddock	OT	right
markhall	markdear	OT	right
cakeshort	cakeclass	OT	right
berrystraw	slashstraw	OT	left
namenick	fivenick	OT	left

(*Appendices continue*)

Appendix A (*continued*)

Reversed compound	Control nonword	Group	Constituent changed
stickchop	brainchop	OT	left
mintpepper	dishpepper	OT	left
flydragon	crydragon	OT	left
doortrap	soontrap	OT	left
brushnail	brushtuft	TT	right
dogsheep	dogpaint	TT	right
chairwheel	chairclasp	TT	right
budrose	budbank	TT	right
plantegg	plantpot	TT	right
postfence	postpause	TT	right
ballsnow	suitsnow	TT	left
fallrain	waitrain	TT	left
washcar	luckcar	TT	left
boyschool	runschool	TT	left
pastetooth	munchtooth	TT	left
snakerattle	flamerattle	TT	left

Note. OO = opaque-opaque compounds; TO = transparent-opaque compounds; OT = opaque-transparent compounds; TT = transparent-transparent compounds.

Appendix B

Prime and Target Stimuli Used in Experiment 2

TARGET	Related prime	Control prime	Condition
BACKFIRE	fireback	svpjzhtd	Compounds
BACKSIDE	sideback	xlrhqfut	Compounds
BLOWFISH	fishblow	ncgmyuvz	Compounds
CAMPFIRE	firecamp	hsuxnqdt	Compounds
CAMPSITE	sitecamp	jlvkxbwu	Compounds
CASEWORK	workcase	dtjnyqvh	Compounds
CHIPMUNK	munkchip	olqyjgsa	Compounds
CONRMEAL	mealcorn	uizjtybf	Compounds
CRAYFISH	fishcray	bxvdkltj	Compounds
DRUMBEAT	beatdrum	vfgsxhnj	Compounds
FISHBOWL	bowlfish	jrtpxvqa	Compounds
FLAGSHIP	shipflag	zvurtjwc	Compounds
FORECAST	castfore	mzdknbhx	Compounds
FOREPLAY	playfore	sxdhcivn	Compounds
GOLDFISH	fishgold	kacnvrqw	Compounds
GRIDLOCK	lockgrid	uptmsxyb	Compounds
HANDPICK	pickhand	eborugzv	Compounds
HANDSOME	somehand	icbujkrl	Compounds
HANGOVER	overhang	jpcxqyud	Compounds
HEADLONG	longhead	fjtvqyzb	Compounds
HOMESICK	sickhome	jdnatbzq	Compounds
HOMEWARD	wardhome	blkfyvij	Compounds
HUMPBACK	backhump	qwsiryne	Compounds
INCHWORM	worminch	syuaexzv	Compounds
LEFTWARD	wardleft	bvjxchsu	Compounds
LIFEBOAT	boatlife	zvnhxysr	Compounds
LOVEBIRD	birdlove	qkwpyfxh	Compounds
LOVESICK	sicklove	hbqjuxpn	Compounds
LUKEWARM	warmluke	qyxjgpfh	Compounds
OVERCAST	castover	fmwxzyju	Compounds
PONYTAIL	tailpony	zuxvhbre	Compounds
POSTCARD	castpost	zlfuwqgj	Compounds
POSTMARK	markpost	fgbdjchu	Compounds
PUSHOVER	overpush	qxzdiwjb	Compounds

(*Appendices continue*)

Appendix B (*continued*)

TARGET	Related prime	Control prime	Condition
SHIPYARD	yardship	bflqgwze	Compounds
SHOPLIFT	liftshop	gnvqjuxc	Compounds
SHOWGIRL	girlshow	udzjvepk	Compounds
SHUTDOWN	downshut	plmfbgqj	Compounds
SIDEWALK	walkside	nvfhuojq	Compounds
SILKWORM	wormsilk	tabgjfhe	Compounds
SLIPKNOT	knotslip	wuxrcdge	Compounds
SOFTWARE	waresoft	bmluqcpk	Compounds
SOMEWHAT	whatsome	updjcngq	Compounds
TAPEWORM	wormtape	xnqjylhv	Compounds
TEAMWORK	workteam	iczguvxh	Compounds
VINEYARD	yardvine	fquwpotk	Compounds
WISHBONE	bonewish	ykzcmxdu	Compounds
YOURSELF	selfyour	ckhjtdbp	Compounds
ASTEROID	roidaste	qpgxlzbk	Monomorphemic
BARITONE	tonebari	suyzchmw	Monomorphemic
BUNGALOW	alowbung	mivjhkry	Monomorphemic
CAMISOLE	solecami	knuvtxzg	Monomorphemic
CAROUSEL	uselcaro	pdgyibnw	Monomorphemic
CATEGORY	gorycate	ilfwzksn	Monomorphemic
CAULDRON	droncaul	vmijqysw	Monomorphemic
CHAMPION	pioncham	xvwsyfzd	Monomorphemic
CHLORINE	rinechlo	bpvadxwq	Monomorphemic
CLARINET	inetclar	psxyumbo	Monomorphemic
COMPLAIN	laincomp	reuwkszt	Monomorphemic
CONTRAST	rastcont	dfghqebl	Monomorphemic
DEMOCRAT	cratdemo	lxsjhqzg	Monomorphemic
DIAGNOSE	nosediag	qxlvyzwp	Monomorphemic
DIALOGUE	oguedial	pxtywnbk	Monomorphemic
DINOSAUR	saurdino	cwmfgvey	Monomorphemic
DOCTRINE	rinedoct	qkvulphx	Monomorphemic
DYNAMITE	mitedyna	xwcugpvf	Monomorphemic
FLAMENCO	encoflam	zkigpsyw	Monomorphemic
FLAMINGO	ingoflam	scwyrtuv	Monomorphemic
HOSPITAL	italhosp	zgxqrydv	Monomorphemic
JEOPARDY	ardyjeop	fzcwvbkg	Monomorphemic
JUBILANT	lantjubi	qyderzxg	Monomorphemic
MAHOGANY	ganymaho	wjczqsur	Monomorphemic
MANICURE	curemani	hzyspkfo	Monomorphemic
MAVERICK	rickmave	yplxtjwb	Monomorphemic
MERCHANT	hantmerc	sifxpdqu	Monomorphemic
MINSTREL	trelmins	hdoqupzc	Monomorphemic
MUSTACHE	achemust	kbqnziyd	Monomorphemic
NEIGHBOR	hborneig	cltxzwpk	Monomorphemic
OBITUARY	uaryobit	nfglxmkd	Monomorphemic
PARTICLE	iclepart	woubmfhn	Monomorphemic
PLATFORM	formplat	enbwvuhc	Monomorphemic
PLATINUM	inumplat	wrszqjhe	Monomorphemic
PLETHORA	horaplet	jmgqfscn	Monomorphemic
PRACTISE	tiseprac	vykdbxmh	Monomorphemic
PREGNANT	nantpreg	hqlbzuxo	Monomorphemic
PROVINCE	inceprov	kgmxltjy	Monomorphemic
PURCHASE	hasepurc	blqytwid	Monomorphemic
SANDWICH	wichsand	klbfgeqt	Monomorphemic
SCENARIO	arioscen	gkhybxwu	Monomorphemic
SHRAPNEL	pnelshra	dykqmgfo	Monomorphemic
SOUVENIR	enirsouv	jyltchwm	Monomorphemic
SPRINKLE	nklespri	mcwbtdzo	Monomorphemic
SYNDROME	romsynd	czvxtlpq	Monomorphemic
THOUSAND	sandthou	rbpzqvjm	Monomorphemic
TRANQUIL	quiltran	hzmpxyge	Monomorphemic
VERBATIM	atimverb	foxwpdlg	Monomorphemic

(*Appendices continue*)

Appendix C

Prime and Target Stimuli Used in Experiment 3

TARGET	Related prime	Control prime	Condition
AIRPLANE	planeair	xftmbuhy	Compounds
ARMCHAIR	chairarm	odjnqvks	Compounds
BACKFIRE	fireback	znmhvxwq	Compounds
BEEHIVE	hivebee	glorcxy	Compounds
BLOWFISH	fishblow	kjtpdzun	Compounds
CAMPSITE	sitecamp	nyhwlrfg	Compounds
COCKPIT	pitcock	xnegqhv	Compounds
CORNMEAL	mealcorn	xpzhwqgv	Compounds
DOUGHNUT	nutdough	feljswrb	Compounds
EARSHOT	shotear	mvwdzfx	Compounds
EYEBROW	broweye	atlnvmf	Compounds
FAIRWAY	wayfair	sgecvnp	Compounds
FLAGSHIP	shipflag	nobrvzyw	Compounds
HAIRCUT	cuthair	gvozpex	Compounds
HANDBAG	baghand	joksxie	Compounds
HEDGEROW	rowhedge	ivkfsblp	Compounds
KEYBOARD	boardkey	jlgsnuxh	Compounds
LIPSTICK	sticklip	dvrbhjfg	Compounds
MIDNIGHT	nightmid	wefsbpxq	Compounds
MOONLIT	litmoon	pfadgyr	Compounds
OUTRIGHT	rightout	kdcwjmpv	Compounds
PAYROLL	rollpay	udcvqjt	Compounds
PINPOINT	pointpin	ygrhujza	Compounds
PLAYBOY	boyplay	vfctjrw	Compounds
PLYWOOD	woodply	qzbvktu	Compounds
POSTMAN	manpost	ckierqh	Compounds
RAGTIME	timerag	dnvlbjy	Compounds
SAUCEPAN	pansauce	hlbgkxid	Compounds
SAWDUST	dustsaw	ovhfkic	Compounds
SKYLIGHT	lightsky	dmjrxuzo	Compounds
SOFTWARE	waresoft	ipxyvczu	Compounds
SOMEWHAT	whatsome	unxfckyq	Compounds
SUNRISE	risesun	ovmcdgz	Compounds
TEASPOON	spoontea	fdzuqbkw	Compounds
VINEYARD	yardvine	gqxzwcms	Compounds
WEDLOCK	lockwed	ypfuibr	Compounds
WEEKEND	endweek	jqimouc	Compounds
YOURSELF	selfyour	vgpabxnc	Compounds
BLANKET	ketblan	rpmifuq	Monomorphemic
CAULDRON	droncaul	zxvqhfpm	Monomorphemic
CHAMPION	pioncham	ysfzugte	Monomorphemic
CHARTER	terchar	muzvwsk	Monomorphemic
COMFORT	fortcom	jhwqgzb	Monomorphemic
CONCERT	certcon	swykubv	Monomorphemic
CONSIST	sistcon	lefkjdh	Monomorphemic
CONTRAST	trastcon	qhzxwkel	Monomorphemic
DOCTRINE	trinedoc	wxalqjyv	Monomorphemic
FOUNTAIN	tainfoun	dryzxkep	Monomorphemic
FURNACE	nacefur	wbzphok	Monomorphemic
JOURNAL	naljour	emhkwci	Monomorphemic
LANTERN	ternlan	qwsijxf	Monomorphemic
LECTURE	turelec	pmgdzox	Monomorphemic
MERCHANT	chantmer	gosijdbw	Monomorphemic
MINSTREL	strelmin	wxvpokbf	Monomorphemic
MOUNTAIN	tainmoun	hcydbplg	Monomorphemic
NEIGHBOR	borneigh	mpuyqsja	Monomorphemic

(*Appendices continue*)

Appendix C (*continued*)

TARGET	Related prime	Control prime	Condition
PASTURE	turepas	jyzgilw	Monomorphemic
PLATFORM	formplat	ugswxhei	Monomorphemic
PORTRAIT	traitpor	zublyvfg	Monomorphemic
PRACTICE	ticeprac	hnwkgbxd	Monomorphemic
PRECISE	cisepre	vwotluq	Monomorphemic
PREGNANT	nantpreg	vykdliwo	Monomorphemic
PURCHASE	chasepur	mbvjyqgf	Monomorphemic
QUARTER	terquar	hklgcdm	Monomorphemic
SANDWICH	wichsand	ebogflrk	Monomorphemic
SEGMENT	mentseg	aifculq	Monomorphemic
SHELTER	tershel	bfnupgi	Monomorphemic
SHRAPNEL	nelshrap	ctugkxjm	Monomorphemic
SPLENDID	didsplen	tygabkuo	Monomorphemic
STANDARD	dardstan	qewblyzx	Monomorphemic
SYNDROME	dromesyn	kzqbhcli	Monomorphemic
THUNDER	derthun	jkzxcva	Monomorphemic
TRACTOR	tortrac	yqdzpxk	Monomorphemic
TRANQUIL	quiltran	fyomsepj	Monomorphemic
TURMOIL	moiltur	eqvhykj	Monomorphemic
WHISPER	sperwhi	gfbulkm	Monomorphemic

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