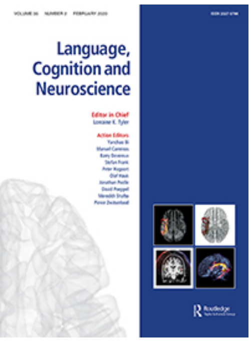

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Evidence for embedded word length effects in complex nonwords

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ABSTRACT
Recent evidence points to the important role of embedded word activations in visual word recognition. The present study asked how the reading system prioritises word identification when not just one, but two different words are embedded within the same position. This question was addressed by using a masked primed lexical decision task (Experiment 1) with target words embedded in nonword primes (*tea* or *team* in *teamaction*). Results revealed priming independently of the length, position, or morphological status of the embedded word. However, when primes were used as targets within a word naming task (Experiment 2), participants were more likely to name the longer than the shorter embedded word, independent of morphological status. Our results suggest that the reading system gives priority to longer embedded words, which we discuss in the context of recent theories of visual word recognition.

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Masked priming; lexical decision; word naming; embedded word identification; embedded word length

The question of how embedded words influence reading is of fundamental interest to morphologists whose research concerns words embedded in complex contexts (e.g. the *teach* in *teacher*). In morphological research, the importance of embedded word processing is immediately obvious (e.g. Diependaele, Sandra, & Grainger, 2009; Grainger & Beyersmann, 2017; Taft, 2003), because the recognition of embedded words facilitates the segmentation into morphemes (e.g. *teach* + *er*) and access to semantics (e.g. a *teacher* is someone who *teaches*). Yet, the activation of embedded words is not unique to morphologically complex words, as has been revealed in studies examining simple word reading (e.g. Bowers, Davis, & Hanley, 2005; Nation & Cocksey, 2009; Snell, Grainger, & Declerck, 2018; Taft, Xu, & Li, 2017).

Previous work from masked priming suggests that the activation of embedded words is an automatic process that happens extremely rapidly during the initial stages of visual word recognition (e.g. Longtin, Segui, & Hallé, 2003; Rastle & Davis, 2008; Rastle, Davis, & New, 2004). The automaticity of embedded word activations has been most effectively demonstrated by testing priming effects from target-embedded nonword primes (e.g. *farmald-FARM*), where the prime is not a lexical competitor of the embedded target word, and therefore the activation of the embedded word can proceed in an uninhibited fashion (e.g. Beyersmann, Casalis, Ziegler, & Grainger, 2015; Beyersmann, Cavalli, Casalis, & Colé, 2016; Hasenäcker, Beyersmann, & Schroeder, 2016; Heathcote, Nation, Castles, & Beyersmann, 2018; Morris, Porter, Grainger, & Holcomb, 2011; Taft, Li, & Beyersmann, 2018). Embedded word priming effects have not just been reported with affixed and non-affixed nonwords (e.g. “farmity-FARM” and “farmald-FARM”; Beyersmann et al., 2015), but also with compound and non-compound nonwords (e.g. “farmbook-FARM” and “farmbolk-FARM”; Beyersmann et al., 2018), suggesting that embedded words are activated independently of whether they occur in combination with a morphemic or non-morphemic unit. This suggests that the activation of embedded words is an entirely non-morphological process (Grainger & Beyersmann, 2017) by which the letters of an input letter-string are mapped onto existing lexical representations that match the letters of the input string.

The evidence for morphology-independent embedded word activations in complex nonwords differs from, but is not inconsistent with, the evidence for morphological decomposition of complex words. Affixed and pseudo-affixed words (*farmer-FARM* and *corner-CORN*) typically yield more priming than non-affixed words (*cashew-CASH*) suggesting that the presence of an affix facilitates access to the embedded stem, at least when the prime is a real word (Beyersmann, Ziegler, et al., 2016; Longtin et al., 2003; Rastle

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et al., 2004; Rastle & Davis, 2008). Similarly, studies investigating compound words (Beyersmann, Grainger, & Castles, 2019; Fiorentino & Fund-Reznicek, 2009) have reported significant priming with transparent and opaque compound words (e.g. *farmhouse-FARM* and *butterfly-BUTTER*), but not with non-compound words (e.g. *sandwich-SAND*). Such results with compound words are therefore similar to the automatic segmentation effects observed in affixed words (e.g. Beyersmann, Ziegler, et al., 2016; Rastle et al., 2004), suggesting that adults automatically activate the embedded word constituents whenever the prime can be exhaustively decomposed into morphemic sub-units.

The key difference in the pattern of priming seen with complex nonword and complex word primes is the absence of priming with non-morphemic words (*sandwich-SAND*) on the one hand, and the presence of priming with non-morphemic nonwords (*sandald-SAND*) on the other. One explanation for these differences is that the degree of lexical interference between the embedded word (*sand*) and the whole letter string (*sandwich*) determines whether or not the activation of the embedded word can proceed in an uninhibited fashion (Grainger & Beyersmann, 2017). In contrast to nonword primes, word primes provide some degree of lexical interference to the embedded words, which therefore explains the absence of priming from *cashew* to *cash*. What complicates the picture, however, is that, as the above evidence shows, there is priming from morphologically complex (*farmer-FARM* and *farmhouse-FARM*) and pseudo-complex word primes (*corner-CORN* and *butterfly-BUTTER*), despite the suspected degree of lexical interference between the embedded word and the whole word. Such morphological and pseudo-morphological word priming effects suggests that whenever the activation of an embedded word unit is hindered, the reading system rapidly applies a morphological analysis to the letter string to segment it into any embedded morphemic units that might exist. In other words, these studies provide evidence for the additional involvement of morphemic units when the input word is a morphologically complex real word. It thus appears that there are two separate mechanisms at play, one that activates embedded words by mapping letters onto existing word representations in the orthographic lexicon irrespective of morphology, and one that decomposes complex words into morphemic sub-units.

A question that arises from these prior findings is at what level in the processing system the pre-activation of an embedded word occurs. Beyersmann et al. (2018) reported significant priming effects for words that were embedded in edge-aligned position of a nonword prime (e.g. *pimebook-BOOK*). Priming did not reach significance with words embedded in edge-aligned but non-contiguous position (e.g. *bopimeok-BOOK*) or in contiguous but non-edge-aligned position (e.g. *pibookme-BOOK*), suggesting that orthographic overlap between the prime and the target is not sufficient to pre-activate the representation of the embedded target word. Instead, the reading system appears to give priority to words embedded in edge-aligned position (see Grainger & Beyersmann, 2017, for a detailed proposal), presumably due to the likely occurrence of stem morphemes in outer string positions (i.e. left-aligned in suffixed words and right-aligned in prefixed words). What complicates the picture, however, is that more often than not, several embedded words can be found in the same edge-aligned position, such as *tea* and *teach* in *teacher*, yet we know very little about how the reading system handles such a situation. Would the representations of any edge-aligned embedded word be pre-activated, or would only the strongest representation be pre-activated?

In the present study, we address this question by using words embedded in nonword strings**.** As the prior literature shows, nonwords provide the ideal context in which to examine the role of embedded words during reading, because they do not lexically inhibit their embedded components. In particular, we were interested in whether or not the length of the embedded word determines how strongly it is activated during visual word recognition. From a morphological point of view, the longer embedded unit is typically the one that forms the morphemic stem of a complex word. For instance, the stem of the suffixed word *farmer* is *farm* (and not *far*) and the stem of compound word *bathtub* is *bath* (and not *bat*). Similarly, in prefixed words, the longer embedded unit typically forms the morphemic stem (e.g. the stem of *prepaid* is *paid* and not *aid*). The case where the shorter embedded word forms a morphemic unit is extremely rare in a language like English because it requires conditions that rarely occur. In particular, it requires that the first letter of a suffix is a consonant that happens to create a real word when added to the last letter of the stem, or that the final consonant of a prefix creates a word when added to the first letter of the stem. There are very few such words, with some of the rare examples being the suffixed word *earless* (meaning "without ears" rather than "a female earl") and the prefixed word *misprint* where it is *print* that is affixed and not *sprint*. It is also very hard to find compound words where the shorter embedded word forms a constituent and the additional letter of the longer embedded word is found in the other constituent (e.g. *tearoom*, where *tea* rather than *tear* forms the first constituent, and *lamplight* where *light* rather than *plight* forms the second constituent). It is therefore possible that the reading system gives priority to longer embedded units compared to shorter ones.

To test this hypothesis, we designed a masked nonword priming study in which the impact of a compound nonword prime was examined when the target was the shorter word embedded in the prime (*teamaction-TEA*) compared to when it was the longer word embedded in the prime (*teamaction-TEAM*). As opposed to previous masked nonword priming studies that standardly focussed on nonwords with single word embeddings, our study was specifically designed to test nonwords with two different word embeddings within the same edge-aligned position of the letter string. Moreover, to examine the role of morphemic status across conditions, half of the targets formed a morphemic constituent of the prime and half of the targets formed a non-morphemic constituent of the prime. In the morphemic compound nonword condition, the prime consisted of two morphemic constituents, with the first constituent being identical to the target (e.g. *teamaction-TEAM* where the prime consisted of *team* + *action*; or *teamission-TEA* where the prime consisted of *tea* + *mission).* In the non-morphemic compound nonword condition, the primes belonged to the opposite condition. For instance, *teamission-TEAM* and *teamaction-TEA* were now non-morphemic items, because **ission* and **maction* are nonwords. Priming was measured by comparing each related prime (e.g. *teamaction-TEAM*) to an unrelated control condition (e.g. *boldfinger-TEAM*).

If the reading system does indeed give priority to longer over shorter embedded words, we would expect to see significantly larger priming in the long compared to shorter embedded word condition. Moreover, although embedded-word priming effects mostly appear to occur independently of morphemic status (e.g. Beyersmann, Cavalli, et al., 2016; Heathcote et al., 2018; Morris et al., 2011), it has been shown that morphological information can help to compensate when the activation of the embedded word is hindered (Grainger & Beyersmann, 2017). We therefore asked if morphemic status acts as a facilitatory factor when two ambiguous words are embedded within the same letter string. As such, morphological information would be used to give preference to the embedded word that coincides with the morphemic boundary (e.g. *team* in *teamaction*) compared to the word that does not coincide with the morphemic boundary (e.g. *tea* in *teamaction*), thus leading to increased priming in the morphemic (*teamaction-TEAM*) compared to the non-morphemic condition (*teamaction-TEA*).

A further goal of our study was to examine differences between words embedded at the beginning of a letter string compared to words embedded at the end. Taft and Forster (1976) found greater interference in a lexical decision task from compound nonwords when made up of a word plus nonword (e.g. *footmilge*) than a nonword plus word (e.g. *trowbreak*), suggesting that words are read in an apparent left-to-right fashion. Similarly, Taft et al. (2017) reported greater interference from words embedded at the beginning of a morphologically simple nonword (e.g. *fur* in *furb*) than from those embedded at the end (e.g. *lid* in *clid*). Moreover, letter visibility seems to be greater in initial than in final position (e.g. Grainger, Bertrand, Lété, Beyersmann, & Ziegler, 2016; Marzouki & Grainger, 2014; Scaltritti & Balota, 2013), which might explain the lesser impact of words embedded in final string position (Taft et al., 2017). However, evidence from masked priming studies that have directly contrasted initial and final word embeddings (e.g. *textbook-TEXT* vs *textbook-BOOK*) show that the activation of the embedded word is equally effective whether they are in initial or final position (e.g. Beyersmann et al., 2018; Beyersmann, Cavalli, et al., 2016; Crepaldi, Rastle, Davis, & Lupker, 2013; Heathcote et al., 2018). Moreover, the masked morphological priming literature provides numerous examples where morphemic units in final string position (i.e. suffixes) are efficiently chunked (Beyersmann, Ziegler, et al., 2016; Rastle et al., 2004; Rastle & Davis, 2008; Taft, 2003, 2004), suggesting that the reading system applies a unitisation process to higher order letter sequences in that position.

From these results, it is clear that, although a left-to-right reading bias exists in visual word recognition, which is particularly evident in overt presentation tasks such as unprimed lexical decision, the early automatic activation of embedded words is not restricted to words in initial string position. Instead, it appears to be a process which is effective for units embedded at both edges of the letter string (Fischer-Baum, Charny, & McCloskey, 2011). The "both-edges" coding scheme proposed by Fischer-Baum et al. (2011) suggests that spaces surrounding written words provide anchor points that can be used to infer letter order information (see also Hannagan & Grainger, 2012; Jacobs, Rey, Ziegler, & Grainger, 1998). According to this scheme, letter order is encoded running forwards from the left edge of the string and running backwards from the right edge of the string. The theoretical framework presented by Grainger and Beyersmann (2017) extends the both-edges coding scheme to the context of more complex words containing word embeddings. The edge-aligned embedded-word activation scheme is based on the idea that forward-running orthographic encoding facilitates the activation of left-aligned embedded words, whereas backward-running orthographic encoding facilitates the activation of right-aligned embedded words.

Therefore, aside from our key interest in the effect of morphological status and embedded word length in this study, we asked whether the reading system attempts to resolve the ambiguity between two different embedded words by falling back onto a more thorough left-to-right scanning mechanism. To address this question, half of our target words were embedded in initial string position and the other half in final string position, which either formed a morphemic constituent (e.g. *teamaction-TEAM, jardrug-DRUG*) or a non-morphemic constituent of the prime (e.g. *teamission-TEAM, yardrug-DRUG*). If left-to-right orthographic processing is indeed used to more carefully evaluate ambiguous word embeddings, left-aligned embedded words would be more readily activated than right-aligned embedded words, thus leading to increased priming effects for words in initial string position.

Experiment 1

Method

Participants

The participants were 120 students from the University of New South Wales, all English native speakers, who participated for course credit or monetary reimbursement.

Materials

A list of 60 words was selected from the CELEX lexical database (Baayen, Piepenbrock, & van Rijn, 1993), which were 4–7 letters long and contained an embedded word that was 1–2 letters shorter (e.g. *team* contained *tea*; *drug* contained *rug*, etc.). Half of these words contained their embedded word at the beginning (e.g. *tea* in *team*) and half at the end (e.g. *rug* in *drug*). The selected words were then used to create two different sets of prime-target pairs (Set 1 and Set 2). The longer words (e.g. *team* and *drug*) served as target words in Set 1 and the shorter words (e.g. *tea* and *rug*) served as target words in Set 2. Each target word was then combined with another word to form a nonword prime consisting of two embedded words (i.e. a so-called "compound nonword"). For instance, the word *action* was added after *team* (giving *teamaction*) and *mission* was added after *tea* (giving *teamission*). Similarly, *jar* was added before *drug* (giving *jardrug*) and *yard* was added before *rug* (giving *yardrug*). Important in this nonword creation process was the fact that both target words were contained in both nonwords (e.g. *team* and *tea* are contained in both *teamaction* and *teamission*, while *drug* and *rug* are contained in both *jardrug* and *yardrug*).

Table 1. Item descriptives of the targets words (top half) and second prime constituents (bottom half) used in Experiment 1.

Type	Word frequency	Number of letters	Example
Target words			
long, beginning	4.1	4.5	*team* (as in *teamaction*)
long, end	4.4	5.3	*drug* (as *jardrug*)
short, beginning	3.9	3.4	*tea* (as in *teamission*)
short, end	4.6	4.2	*rug* (as in *yardrug*)
Second prime constituent			
short, end	3.6	4.6	*action* (as in *teamaction*)
short, beginning	3.5	3.8	*jar* (as in *jardrug*)
long, end	3.3	5.7	*mission* (as in *teamission*)
long, beginning	3.5	4.9	*yard* (as in *yardrug*)

When taking the word target into account, these nonword primes corresponded to either a morphemic condition (where primes were composed of the target word and another word) and a non-morphemic condition (where primes were composed of the target word and a nonword). The exact same primes were used in Set 1 and Set 2. However, in Set 1, the longer target words determined the morphemic status of the prime (i.e. *teamaction-TEAM* and *jardrug-DRUG* were morphemic while *teamission-TEAM* and *yardrug-DRUG* were non-morphemic), whereas in Set 2, the shorter target words determined morphemic status (i.e. *teamission-TEA* and *yardrug-RUG* were morphemic while *teamaction-TEA* and *jardrug-RUG* were non-morphemic).

The morphemic and non-morphemic conditions were compared against an unrelated control condition, in which compound nonword primes were created by combining two unrelated constituents. As in the related conditions, the primes in the unrelated control condition were also identical in both Sets 1 (e.g. *boldfinger-TEAM*, *cupfork-DRUG*) and Set 2 (e.g. *boldfinger-TEA*, *cupfork-RUG*).

The three different primes (morphemic vs. non-morphemic vs. unrelated) were identical in length (e.g. *teamaction* vs. *teamission* vs. *boldfinger*; *jardrug* vs *yardrug* vs *cupfork*). The long and short targets (i.e. Sets 1 and 2) were matched overall on word frequency (all p's $> .1$), as were the items with initial embeddings (e.g. *team*) and items with final embeddings (e.g. *drug*) (see Table 1). A full list of stimuli can be found in Appendix A.

For the purpose of the lexical decision task, 60 nonword targets were included (e.g. *porf, phard, etc.*), which were orthographically legal and pronounceable and matched on length to the real-word targets. For each nonword target, a nonword prime was created consisting of a word and a nonword constituent. Half of the nonwords contained the target in initial position, while the other half contained the target in final position. The beginning-items were subdivided into the following categories: 10 primes consisted of the nonword target plus a word (e.g. *phardright-PHARD*), 10 consisted of the nonword target plus a nonword (e.g. *snirpress-SNIRP*), and 10 were unrelated primes consisting of a nonword plus a real word (e.g. *slorandom-BLUNK*). The remaining 30 nonword primes were ending-items, and structured following the same principles as the beginning-items (10 like *clusternort-NORT*, 10 like *proudreak-DREAK*, and 10 like *captrimp-PLIGONE*). The exact same nonword primes were used in Sets 1 and 2, but the nonword targets differed in length (e.g. *phardright-PHARD* was used in Set 1 and *phardright-PHAR* in Set 2). Sixty participants were presented with the Set 1 materials and 60 with the Set 2 materials. To avoid target repetition, a Latin Square design was used to create three counterbalanced lists for each item set.

Procedure

Stimuli were presented in the centre of a LCD computer screen using DMDX software (Forster & Forster, 2003). Each trial consisted of a 500-ms forward mask of hash keys, then a 50-ms prime in lowercase, then the uppercase target. The target remained present until the response was made or until 3 s had elapsed. Participants were instructed to respond as quickly and accurately as possible.

Results and discussion

Lexical decisions to word targets were analyzed as follows. Seven target words were removed because error rates were above 40% (all highlighted with an asterisk in the appendix). Incorrect responses were removed from the reaction time (RT) analysis (7.1% of all data), and inverse RTs (1/RT) were calculated for each participant to correct for RT distribution skew. Reaction times smaller than 200 ms and longer than 2000 ms were excluded from the analyses (0.1% of the data). RTs and error rates are presented in Table 2 and were analyzed for each subject.

We used linear mixed-effect modelling to perform the main analyses (Baayen, 2008; Baayen, Davidson, & Bates, 2008). Trial order was included to control for longitudinal task effects such as fatigue or habituation. Following Barr, Levy, Scheepers, and Tily (2013), we included the maximal random effect structure justified by the design. A linear mixed-effects model, as implemented in the *lme4* package (Bates, Maechler, Bolker, & Walker, 2014) in the statistical software R (Version 3.0.3; RDevelopmentCoreTeam, 2019) was created with four fixed effects factors which were Prime Type (morphemic, non-morphemic, unrelated), Embedded Word Length (long, short), Embedded Word Position (initial, final), and Trial Order. Also included were the interaction between Prime Type, Embedded Word Length and Embedded Word Position, the interaction between Prime Type and Embedded Word Length, the interaction between Prime Type and Embedded Word Position, as well as random intercepts and random slopes for subjects and items. The *lmerTest* package (Kuznetsova, Brockhoff, & Christensen, 2017) was used to compute *p*-values and the *brms* package (Buerkner, 2017) to compute Bayes Factor (BF) analyses. The full initial model was refitted after excluding data-points whose standardised residuals were larger than 2.5 in absolute value (2.4%; see Baayen, 2008). Following this outlier trimming, a backward stepwise model selection procedure was used, and fixed effects were only included if they significantly improved the model's fit. Models were selected using chi-squared log-likelihood ratio tests with regular maximum likelihood parameter estimation.

In the RT analyses, the model's fit was not improved by the inclusion of the interactions, nor by the inclusion of factors Embedded Word Position and Embedded Word Length, which were therefore excluded from the analyses. To further test the strength of evidence for the absence of interactions, a set of Bayesian multilevel model analyses were conducted to compare (i) a model including the Prime Type * Embedded Word

Table 2. Mean reaction times (in ms) and error rates (in %), averaged across participants.

	Reaction times (ms)		Error rates (%)		
	Initial embedding	Final embedding	Initial embedding	Final embedding	Example
			longer embedded words (Set 1)		
morphemic	613 (103)	610 (103)	5.8 (8.9)	6.9 (8.8)	*teamaction-TEAM/jardrug-DRUG*
non-morphemic	609 (101)	612 (95)	7.2 (8.8)	6.8 (10.8)	*teamission-TEAM/yardrug-DRUG*
unrelated	625 (107)	627 (89)	9.2 (11.6)	6.3 (8.1)	*boldfinger-TEAM/woodarm-DRUG*
			shorter embedded words (Set 2)		
morphemic	592 (70)	606 (65)	8.0 (11.6)	8.9 (11.2)	*teamission-TEA/yardrug-RUG*
non-morphemic	591 (71)	600 (80)	4.9 (7.4)	6.5 (9.8)	*teamaction-TEA/jardrug-RUG*
unrelated	599 (81)	617 (81)	9.0 (12.4)	8.9 (10.5)	*boldfinger-TEA/woodarm-RUG*

Note: Standard deviations are presented in parentheses.

Length * Embedded Word Position interaction relative to a reduced model including main effects only, (ii) a model including the Prime Type * Embedded Word Length interaction relative to a reduced model including main effects only and (iii) a model including the Prime Type * Embedded Word Position interaction relative to a reduced model including main effects only. All three Bayes Factor analyses revealed strong evidence for the reduced models (i. $BF_{10} = 0.0001$, ii. $BF_{10} = 0.01160$, and iii. $BF_{10} = 0.00366$), which thus confirmed the results of the model selection procedure. The model failed to converge with the inclusion of by-subject and by-item random slopes for Prime Type and Trial order, which were therefore also excluded.

The final model included fixed effect factors Prime Type and Trial Order, as well as random intercepts for subjects and items. There was a significant main effect of Prime Type, $X^2(2) = 24.60$, $p < .001$. Comparing the full Bayesian multilevel model containing Prime Type against a reduced model without Prime Type revealed strong confirmative evidence for the full model ($BF_{10} = 84.67$). Pair-wise comparisons between the three levels of factor Prime Type revealed that participants responded significantly more quickly in the morphemic condition than in the unrelated condition, $t = 3.82$, $p < .001$, and significantly more quickly in the non-morphemic condition than in the unrelated condition, $t = 4.77$, $p < .001$. The difference between the morphemic and non-morphemic conditions was not significant, $t = 0.83$, $p < .407$. The only other significant effect was Trial Order, $X^2(1) = 19.10$, $p < .001$.

Error analyses followed the same logic as the RT analyses. A binomial variance assumption was applied to the trial-level binary data using the function *glmer* as part of the R-package *lme4*. There were no significant effects.

In sum, the results of Experiment 1 demonstrate that robust priming effects emerged regardless of the length, position, or morphemic status of the embedded word. Our data show that the early stages of word recognition appear to be sensitive to edge-aligned processing that acts independently from each end (Grainger & Beyersmann, 2017). The key finding is the absence of a length effect, suggesting that both the shorter and the longer embedded words were equally pre-activated in this task.

Experiment 2

To follow up on the absence of a length effect in Experiment 1, we conducted a second experiment, using a word naming task, to establish whether or not a bias toward the longer word can be observed with the same materials that did not show such a bias in the masked priming data of Experiment 1. As opposed to Experiment 1, where compound nonword primes were presented so briefly that participants were not aware of their existence, the compound nonword items in this task were presented as targets and participants were asked to explicitly report one out of the two embedded words that they were able to identify first. This explicit selection task was used to determine the probability by which one out of two embedded words is visually identified. Crucially, the dependent variable in this task was word identification probability, rather than variables capturing the spoken output such as naming speed or naming accuracy. A related word spotting study by Taft and Álvarez (2014) indicated that longer initially embedded words should be preferred over shorter ones because of coda maximisation, whereby the information conveyed by the first syllable is optimised by including all the consonants after the vowel that can form a legal coda. The authors reported that participants were less likely to access shorter words when a longer possibility existed. In that study, participants were asked to report whether there was a word embedded at the beginning of a nonword string – yes or no. Words were missed more often when disguised through coda optimisation than when they were not. For example, fewer people reported seeing *slam* in *slampora* than in *slamorpa*, indicating that they treated the beginning of the former letter-string as *slamp*, hence preventing access to *slam*. That is, even when the longer unit was a nonword, participants were less likely to identify the shorter unit as a word, suggesting that the shorter word is disadvantaged due to coda maximisation rather than lexical competition (*slamp* is not a word and therefore does not lexically compete with *slam*).

The embedded word naming task in Experiment 2 slightly differed from the previously used word spotting paradigm (Alvarez, Taft, & Hernández-Cabrera, 2017; Libben, 1994; Taft & Álvarez, 2014), in the sense that participants were not asked to decide whether or not there was a word embedded in the letter string, but instead had to name the first word they saw at the beginning of the letter string. The items that were the primes of Experiment 1 were presented as 500 ms targets in this task, thus allowing participants to carry out a more thorough analysis of the components of the compound nonwords. Participants had to make an explicit decision as to what the embedded word was, thus providing a direct measure of which embedded word the reader activated first (or most strongly). Since the compound nonwords used in Experiment 1 consisted of two constituents (e.g. *team* + *action*) and our primary interest was in the identification of the ambiguous constituent (*tea/team*) rather than the second unambiguous constituent (*action*), we had to limit the word naming task to words embedded in initial position.

We hypothesised that if there really is a bias toward the longer embedded word, participants would be more likely to name the longer than the shorter embedded word (e.g. *team* rather than *tea* in *teamaction* / *teamission*). In addition, it was determined whether or not morphological structure modulates this putative bias, in which case participants would be more likely to name the longer word when it coincided with a morphemic unit than a non-morphemic unit (e.g. naming *team* rather than *tea* in *teamaction* more often than in *teamission*).

Method

Participants

Thirty-five students from Macquarie University, all English native speakers, participated for course credit or monetary reimbursement.

Materials

The primes of Experiment 1 were used as targets in Experiment 2. However, for the purpose of the embedded word naming task, we only used those that contained a target word in initial string position (see items listed in the top half of Appendix A). This included 30 nonwords in which the longer word formed the morphemic unit (e.g. *teamaction*), 30 nonwords in which the shorter word formed the morphemic unit (e.g. *teamission*) and 30 unambiguous nonwords (e.g. *boldfinger*) which were the unrelated primes from Experiment 1. In addition, we added another set of 30 nonword fillers with unambiguous word embeddings to balance out the number of ambiguous and unambiguous items in the experiment.

Procedure

Stimulus presentation and data recordings were controlled using the DMDX software (Forster & Forster, 2003). Stimuli were presented in the centre of a LCD computer screen. Each trial consisted of a 500-ms fixation cross followed by a 500-ms lowercase target. Participants were instructed to report the first word they spotted at the beginning of the letter string as quickly but as accurately as possible, without any indication given that there was more than one option, and were informed that they had a maximum of 3 s to respond before the experiment automatically moved to the next trial. Participants' responses were recorded with a neck-worn cardiod directional microphone and a tube preamplifier to ensure quality recordings. The dependent variable in this task was the probability of naming the longer and/or morphemic embedded word.

Table 3. Mean embedded word naming probabilities (in %), averaged across participants.

	Longer word is morphemic	Shorter word is morphemic	Across all trials
Probability to name longer word	79.4% (14.3)	82.9% (15.1)	81.1% (12.1)

Note: Standard deviations are presented in parentheses.

Results and discussion

Unambiguous fillers and incorrect responses were removed from the analyses (5.8% of all data). For each condition, we then calculated the mean probability of naming the longer embedded word depending on whether it formed the morphemic versus non-morphemic embedded unit (see Table 3).

Two linear-mixed effects models were created with one fixed effects factor (Condition: longer word is morphemic, shorter word is morphemic), and two random effects factors (random intercepts for subjects and items). In the first model, the dependent variable was morphemic status (i.e. whether or not participants named the morphemic unit) and in the second model the dependent variable was length (i.e. whether or not participant named the longer unit). A binomial variance assumption was applied to the trial-level binary data using the function *glmer* as part of the R-package *lme4*. The results of the first model revealed a significant main effect of condition, showing that participants were more likely to name the morphemic word when it was long (81.1%) than when it was short, $X^2(1) = 9757461$, $p < .001$. Bayesian multilevel model analyses comparing a full model including Condition against a reduced model without Condition revealed strong confirmative evidence for the full model ($BF_{10} = 158203270468.79$). The results of the second model showed that the effect of condition was not significant, $X^2(1) = 0.31$, $p = .576$, suggesting that participants ability to name a word was not influenced by morphemic status. Again, this was confirmed by Bayesian multilevel model analyses, which revealed evidence for the reduced model ($BF_{10} = 1.03$).

The results of Experiment 2 provide clear evidence for an embedded word length bias in the word naming task. The fact that participants were more likely to name the longer embedded word (e.g. *team*) than the shorter one (e.g. *tea*) is consistent with the hypothesis that the reading system gives priority to the longer embedded word, which we discuss in more detail below. The absence of a morphological effect in this task suggests that orthographic parsing tends to take place on a systematic basis that is oblivious to higher-level structure, at least when the input is a nonword string.

General discussion

Two experiments were conducted to examine the influence of length, position, and morphemic status on embedded word activation effects in visual word recognition. In Experiment 1, masked primed lexical decision was used to tap into the early, automatic stages of visual word reading. In Experiment 2, an embedded word naming task was used to directly establish whether it really is the case that there is no bias toward the longer embedded word, and whether or not this bias is modulated by morphological structure. Our studies examined nonwords consisting of two overlapping embedded words (e.g. *tea* and *team* in *teamaction*), which either did or did not coincide with the morphemic boundary of the complex letter string (e.g. *team* in *teamaction* vs. *team* in *teamission*). In addition, we modulated the position of the embedded word in Experiment 1, such that it either occurred in initial or final string position (e.g. *team* in *teamaction* vs. *drug* in *jardrug*). Based on the fact that morphological constituents typically constitute the longer embedded units, we asked if the reading system would give priority to the longer embedded units, and whether or not the process of activating the embedded unit would be modulated by position or morphemic status.

In Experiment 1, priming was observed regardless of length, position, and morphemic status of the embedded word. The absence of a position effect is consistent with previous results from masked morphological priming studies, showing that words embedded in string initial position are activated as much as words embedded in string final position (e.g. Beyersmann, Cavalli, et al., 2016; Crepaldi et al., 2013; Heathcote et al., 2018). These data are in line with the assumptions of the both-edges coding scheme, suggesting that the left and right edges of a letter string are used as anchor points during orthographic encoding (Fischer-Baum et al., 2011). The edge-aligned embedded word activation framework of Grainger and Beyersmann (2017) extends the both-edges coding principle to the context of morphologically complex words by proposing an embedded word identification mechanism that runs forwards from the left edge and backwards from the right edge of the string. A prediction that this account entails is that embedded words are activated more strongly in outer string position than words in mid-string position. Such a coding preference is expected to occur at the early initial orthographic decoding stages, using the spaces on each side of the word as anchor points to infer letter order information. Consistent with this hypothesis, significant masked priming has been reported (Beyersmann et al., 2018) with words embedded in outer-string position (e.g. *pimebook-BOOK*), but not with words embedded in mid-string position (e.g. *pibookme-BOOK*), thus suggesting that edge-alignedness facilitates the activation of embedded words during the early stages of orthographic processing. What is less clear, however, is whether or not the benefit of edge-alignedness persists through to the later stages of visual word recognition. Bowers et al. (2005) showed that semantic congruency effects can be obtained for mid-embedded words as much as for outer embedded words using a semantic categorisation task to elicit semantic processing by providing semantic cues to the embedded target word (e.g. "Does hatch refer to a piece of clothing?"). However, the accuracy data in this study revealed a less convincing effect for centrally or final embedded words (see Taft et al., 2017, for further discussion of the issue). Hence, whether edge-alignedness does or does not modulate embedded word identification to the level of meaning remains debatable and open for future investigation.

The absence of a morphological effect in masked nonword priming also converges with prior findings, suggesting that the activation of words embedded in complex nonwords is not reliant on morphological segmentation (e.g. Beyersmann, Cavalli, et al., 2016; Heathcote et al., 2018; Morris et al., 2011; Taft et al., 2018). Our results extend these prior findings to a context in which two ambiguous words are embedded within the same edge-aligned position of the letter string, and show that both embedded units are equally activated in the reading system without any influence of morphological processing. Of course, the important role for morphological segmentation has been widely established in the reading literature, ever since Taft and Forster's (1975) initial work and later results from masked priming (Beyersmann, Ziegler, et al., 2016; Longtin et al., 2003; Rastle et al., 2004; Rastle & Davis, 2008). Yet our results are not inconsistent with these findings as will now be outlined.

From a theoretical perspective, the divide between the results from studies examining complex real words and studies examining complex nonwords is highly informative and sheds new light onto the mechanisms involved in morphological processing. In complex nonwords, the activation of the embedded word (e.g. *farm* in *farmity*) can proceed without any lexical interference from the whole letter string. In complex words, however, the activation of an embedded word (e.g.

farm in *farmer*) is potentially hindered by the lexical representation of the whole word. Grainger and Beyersmann (2017) argue that whenever the activation of an embedded word unit is hindered, the reading system rapidly applies the principle of full decomposition, which is successful whenever a given the letter string can be exhaustively decomposed into morphemic subunits. This explains why with complex words, significant priming effects only emerge with fully decomposable words (see Rastle & Davis, 2008, for a review), including both truly suffixed (e.g. *farmer-FARM*) and pseudo-suffixed words (e.g. *corner-CORN*), but not non-suffixed words (e.g. *cashew-CASH*). The principle of full decomposition can also account for compound word priming effects (e.g. Beyersmann et al., 2019; Fiorentino & Fund-Reznicek, 2009), where significant priming is typically seen with true compound words (e.g. *farmhouse-FARM*) and pseudo-compound words (e.g. *pineapple-PINE*), but not with non-compound words (e.g. *cardigan-CARD*). One key prediction that can be derived from these prior findings is that larger priming effects should be observed with longer morphemic target words (*farmhouse-FARM* and *pineapple-PINE*) compared with shorter non-morphemic target words (*farmhouse-FAR* and *pineapple-PIN*).

In Experiment 2, morphological status still had no impact on responses, but participants were significantly more likely to name the longer than the shorter embedded unit. One explanation for the embedded word length effect is that longer embedded words are more likely to provide a cue to the morphological and semantic structure of a word, because longer words are more likely to form the morphemic stem of a complex word. For instance, identifying *team* in *teamwork* is more beneficial than identifying *tea* in *teamwork*, because *team* is the morphemic stem which allows segmentation of the input word into *team* and *work* and derive its meaning. The same kind of principle applies to words embedded in string-final position, where identifying *paid* in *prepaid* is more beneficial than identifying *aid* in *prepaid*. This is also in line with the coda maximisation principle of Taft and Álvarez (2014), whereby the information conveyed by the first syllable is optimised by including all the consonants after the vowel that can form a legal coda. Our items were selected such that the longer embedded words always formed the maximised coda. The coda maximisation principle is therefore consistent with the longer word advantage seen in Experiment 2.

What remains to be explained, however, is why the embedded word length effect was not detectable in masked priming. The results of our two experiments indicate that the reading system does indeed seem to give priority to longer embedded words compared to shorter embedded words, but only when participants are given time to thoroughly process the target items, as was the case in Experiment 2. In Experiment 1, primes were presented so briefly (50 ms) that participants only had time for a rather superficial analysis of the input string. It is possible that the observed form of facilitation in this task was simply due to lower level orthographic overlap between the prime and the target. Looking at previous results from masked priming, however, it appears that embedded words are indeed activated to the lexical level even if only briefly presented, as in the context of a lexical decision task using masked priming. Beyersmann and Grainger (2018) showed that priming from non-affixed nonwords was significantly greater when the embedded word had a relatively large morphological family compared with a family limited to the plural form only. Morphological family size effects have been widely replicated (e.g. Bertram, Baayen, & Schreuder, 2000; Juhasz & Berkowitz, 2011; Kuperman, Schreuder, Bertram, & Baayen, 2009) and observed within regular and irregular past participles, suggesting that the effect is not mediated by the exact form of the stem morpheme (De Jong, Schreuder, & Baayen, 2000). What is clear from these prior findings is that the activation of embedded words appears to rapidly proceed beyond the initial level of orthographic form analysis, reflecting the activation of a higher-level abstract central representation that forms the head of a given morphological family. At the same time, the current data suggest that embedded word activation processes are not restricted to the activation of single words during the early stages of word recognition, with shorter and longer as well as morphemic and non-morphemic word embeddings receiving comparable activation strength. One possible reason for why a wide range of embedded word alternatives are initially activated, is that it equips the reading system with a broad choice of potential constituent candidates which can be used to compute meaning during the later stages of word recognition. How exactly the selection and potential competition between different co-activated embedded word candidates is resolved is still an outstanding question for future research. The results of Experiment 2 suggest that embedded word length is at least one crucial factor that determines this process.

In conclusion, the present study used two different experimental paradigms to examine mechanisms of embedded word identification. In line with Grainger and Beyersmann's (2017) theoretical framework, the results show that the activation of embedded words is an entirely non-morphological process. Moreover, the presence of an embedded word length effect in the word naming task

(Experiment 2) in the absence of such an effect in masked priming (Experiment 1) suggests that the word recognition system clearly favours longer over shorter embedded words, but only once a letter string is consciously processed (indeed, the shorter embedded word may not even reach the level of consciousness – see Taft & Álvarez, 2014). Our findings thus highlight the importance and robustness of embedded word activations during the early stages of word recognition, and suggest that embedded word length is a key predictor that determines the identification of embedded words during the later stages of reading.

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No potential conflict of interest was reported by the authors.

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References

Alvarez, C. J., Taft, M., & Hernández-Cabrera, J. A. (2017). Syllabic strategy as opposed to coda optimization in the segmentation of Spanish letter-strings using word spotting. *Scientific Studies of Reading*, *21*(2), 99–108.

Baayen, R. H. (2008). *Analyzing linguistic data: A practical introduction to statistics using R*. Cambridge: Cambridge University Press.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*, 390–412.

Baayen, R. H., Piepenbrock, R., & van Rijn, H. (1993). The CELEX lexical database (CD-ROM).

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory & Language*, *68*(3). doi:10.1016/j.jml.2012.11.001

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-5. Retrieved from http://CRAN.R-project.org/package=lme4

Bertram, R., Baayen, R. H., & Schreuder, R. (2000). Effects of family size for complex words. *Journal of Memory & Language*, *42*, 390–405.

Beyersmann, E., Casalis, S., Ziegler, J. C., & Grainger, J. (2015). Language proficiency and morpho-orthographic segmentation. *Psychonomic Bulletin & Review*, *22*, 1054–1061.

Beyersmann, E., Cavalli, E., Casalis, S., & Colé, P. (2016). Embedded stem priming effects in prefixed and suffixed Pseudowords. *Scientific Studies of Reading*, *20*(3), 220–230. doi:10.1080/10888438.2016.1140769

Beyersmann, E., & Grainger, J. (2018). Support from the morphological family when unembedding the stem. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *44*(1), 135–142.

Beyersmann, E., Grainger, J., & Castles, A. (2019). Embedded stems as a bootstrapping mechanism for morphological parsing during reading development. *Journal of Experimental Child Psychology*, *182*, 196–210. doi:10.1016/j.jecp.2019.01.010

Beyersmann, E., Kezilas, Y., Coltheart, M., Castles, A., Ziegler, J. C., Taft, M., & Grainger, J. (2018). Taking the book from the bookshelf: Masked constituent priming effects in compound words and nonwords. *Journal of Cognition*, *1*(1), 10.

Beyersmann, E., Ziegler, J. C., Castles, A., Coltheart, M., Kezilas, Y., & Grainger, J. (2016). Morpho-orthographic segmentation without semantics. *Psychonomic Bulletin & Review*, *23*, 533–539. doi:10.3758/s13423-015-0927-z

Bowers, J. S., Davis, C. J., & Hanley, D. A. (2005). Automatic semantic activation of embedded words: Is there a 'hat' in 'that'? *Journal of Memory & Language*, *52*, 131–143.

Buerkner, P.-C. (2017). Brms: An *R* package for Bayesian multilevel models using stan. *Journal of Statistical Software*, *80*(1), 1–28. doi:10.18637/jss.v080.i01

Crepaldi, D., Rastle, K., Davis, C. J., & Lupker, S. J. (2013). Seeing stems everywhere: Position-independent identification of stem morphemes. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(2), 510–525.

De Jong, N. H., Schreuder, R., & Baayen, R. H. (2000). The morphological family size effect and morphology. *Language and Cognitive Processes*, *15*(4/5), 329–365.

Diependaele, K., Sandra, D., & Grainger, J. (2009). Semantic transparency and masked morphological priming: The case of prefixed words. *Memory & Cognition*, *37*, 895–908.

Fiorentino, R., & Fund-Reznicek, E. (2009). Masked morphological priming of compound constituents. *The Mental Lexicon*, *4*(2), 159–193. doi:10.1075/ml.4.2.01fio

Fischer-Baum, S., Charny, J., & McCloskey, M. (2011). Both-edges representation of letter position in reading. *Psychonomic Bulletin & Review*, *18*(6), 1083–1089. doi:10.3758/s13423-011-0160-3

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers*, *35*(1), 116–124.

Grainger, J., Bertrand, D., Lété, B., Beyersmann, E., & Ziegler, J. C. (2016). A developmental investigation of the first-letter advantage. *Journal of Experimental Child Psychology*, *152*, 161–172.

Grainger, J., & Beyersmann, E. (2017). Edge-aligned embedded word activation initiates morpho-orthographic segmentation.

In B. H. Ross (Ed.), *The Psychology of Learning and Motivation* (Vol. 67, pp. 285–317). San Diego, CA: Academic Press.

Hannagan, T., & Grainger, J. (2012). Protein analysis meets visual word recognition: A case for string kernels in the brain. *Cognitive Science*, *36*, 575–606.

Hasenäcker, J., Beyersmann, E., & Schroeder, S. (2016). Masked morphological priming in German-speaking adults and children: Evidence from response time distributions. *Frontiers in Psychology*, *7*, 929. doi:10.3389/fpsyg.2016.00929

Heathcote, L., Nation, K., Castles, A., & Beyersmann, E. (2018). Do 'blacheap' and 'subcheap' both prime 'cheap'? An investigation of morphemic status and position in early visual word processing. *Quarterly Journal of Experimental Psychology*, *71*(8), 1645–1654.

Jacobs, A. M., Rey, A., Ziegler, J. C., & Grainger, J. (1998). MROM-P: An interactive activation, multiple read-out model of orthographic and phonological processes in visual word recognition. In J. Grainger, & A. M. Jacobs (Eds.), *Localist connectionist approaches to human cognition* (pp. 147–188). Mahwah, NJ: Erlbaum.

Juhasz, B. J., & Berkowitz, R. N. (2011). Effects of morphological families on English compound word recognition: A multitask investigation. *Language and Cognitive Processes*, *26*, 653–682.

Kuperman, V., Schreuder, R., Bertram, R., & Baayen, R. H. (2009). Reading polymorphemic Dutch compounds: Toward a multiple route model of lexical processing. *Journal of Experimental Psychology: Human Perception & Performance*, *35*(3), 876–895.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). Tests in linear mixed effects models. *Journal of Statistical Software*, *82*(13), 1–26.

Libben, G. (1994). How is morphological decomposition achieved? *Language and Cognitive Processes*, *9*, 369–391.

Longtin, C. M., Segui, J., & Hallé, P. A. (2003). Morphological priming without morphological relationship. *Language and Cognitive Processes*, *18*(3), 313–334.

Marzouki, Y., & Grainger, J. (2014). Effects of stimulus duration and inter-letter spacing on letter-in-string identification. *Acta Psychologica*, *148*, 49–55.

Morris, J., Porter, J. H., Grainger, J., & Holcomb, P. J. (2011). Effects of lexical status and morphological complexity in masked priming: An ERP study. *Language and Cognitive Processes*, *26*(4–6), 558–599.

Nation, K., & Cocksey, J. (2009). Beginning readers activate semantics from sub-word orthography. *Cognition*, *110*(2), 273–278. doi:10.1016/j.cognition.2008.11.004

Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language & Cognitive Processes*, *23*, 942–971.

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.

RDevelopmentCoreTeam. (2019). *R: A language and environment for statistical computing*: R version 3.6.0.

Scaltritti, M., & Balota, D. (2013). Are all letters really processes equally and in parallel? Further evidence of a robust first letter advantage. *Acta Psychologica*, *144*, 397–410.

Snell, J., Grainger, J., & Declerck, M. (2018). A word on words in words: How do embedded words affect reading? *Journal of Cognition*, *1*(1), 40.

Taft, M. (2003). Morphological representation as a correlation between form and meaning. In E. Assink, & D. Sandra (Eds.), *Reading complex words* (pp. 113–137). Amsterdam: Kluwer.

Taft, M. (2004). Morphological decomposition and the reverse base frequency effect. *Quarterly Journal of Experimental Psychology*, *57*, 745–765.

Taft, M., & Álvarez, C. J. (2014). Coda optimization in the segmentation of English polysyllabic letter-strings. *Experimental Psychology*, *61*(6), 488–494. doi:10.1027/1618-3169/a000266

Taft, M., & Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Learning Behavior*, *15*, 607–620.

Taft, M., Li, S., & Beyersmann, E. (2018). What cross-morphemic letter transposition in derived nonwords tells us about lexical processing. *Journal of Cognition*, *1*(1), 36. doi:10.5334/joc.39

Taft, M., Xu, J., & Li, S. (2017). Letter coding in visual word recognition: The impact of embedded words. *Journal of Memory and Language*, *92*, 14–25. doi:10.1016/j.jml.2016.05.002