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Do 'blacheap' and 'subcheap' both prime 'cheap'? An investigation of morphemic status and position in early visual word processing

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Abstract

Much research suggests that words comprising more than one morpheme are decomposed into morphemes in the early stages of visual word recognition. In the present masked primed lexical decision study, we investigated whether or not decomposition occurs for both prefixed and suffixed nonwords, and for nonwords which comprise a stem and a non-morphemic ending. Prime-target relatedness was manipulated in the three ways: (1) primes shared a semantically transparent morphological relationship with the target (e.g., *subcheap-CHEAP; cheapize-CHEAP*); (2) primes comprised targets and non-affixal letter strings (e.g., *blacheap-CHEAP; cheapstry-CHEAP*); (3) primes were real, complex words unrelated to the target (e.g., *miscall-CHEAP; idealism-CHEAP*). Both affixed and non-affixed nonwords significantly facilitated the recognition of their stem targets, suggesting that embedded stems are activated independently of whether they are accompanied by a real affix or a non-affix. There was no difference in priming between stems being embedded in initial and final string position, indicating that embedded stem activation is position-independent. Finally, more priming was observed in the semantically interpretable affixed condition than in the non-affixed condition, which points to a semantic licencing mechanism during complex novel word processing.

The study of morphemes - the smallest units of meaning in our language system - is fundamental to linguistic research. One question that forms a core of research in this area is how the brain processes morphemes in the service of reading and understanding written language. Clearly, during the word reading process, some representation of our sensory input must be matched with an internal lexical representation in order to recognise that a sequence of letters forms a word (Taft & Forster, 1975). There has been considerable debate, however, as to whether word recognition is characterised by a level of processing that is specifically morphological - a level at which morphemes are treated differently from whole words - or whether whole-word processing is sufficient (Boudelaa & Marlsen-Wilson, 2005; Frost, Grainger, & Carreiras, 2008; Frost, Grainger, & Rastle, 2005). This distinction is important because it can inform us about the internal structure of the reader's *mental lexicon*, that is, their mental representation of what words look like and what they mean (Marslen-Wilson, Tyler, Waksler, & Older, 1994). Hence, the current study examines the role of morphology during the word reading process, with implications for understanding the mental lexicon.

Morphology is at the heart of complex written language. It is so integral, in fact, that many of the words you will read in this sentence alone can be decomposed into at least two morphemes. Consider the word *decomposed*, for example, which comprises the stem *compose*, the inflectional suffix *–(e)d*, and the negative prefix *de-*. It seems crucial for the visual word processing system to make use of these rules of word formation to capitalise on storage space, and to understand new words (e.g., George Bush's 2000 claim 'They *misunderestimated* me'). However, the English language (among most European languages) also contains many words which are 'misleading' in their morphology. For example, the word *corner* seemingly comprises two morphemes, *corn* and *–er*. However, this apparent complexity is deceptive, as a *corner* is not 'someone who *corns*,' which we would expect given the function of the *–er* suffix. It is not surprising, then, that morphology has been a central topic of psycholinguistic research for over 35 years (see Taft & Forster, 1975).

We build on the extant literature using the masked priming paradigm, developed by Forster and Davis (1984), as this has provided one of the most fruitful techniques for investigating morphology to date. In a typical masked priming trial, a prime (e.g., *cleaner*) is sandwiched between a forward mask (#####) and a target (e.g., *CLEAN*). The participant is then asked to make a lexical decision on the target (is *clean* a word?). Participants are unable to name the prime (Forster, Davis, Schoknecht, & Carter, 1987) and the brief presentation duration of the prime (around 50ms) is argued to be below the threshold of conscious detection. This means that the prime cannot be used strategically when making a decision about the target stimulus. Nor are participants likely to be influenced by an episodic trace of the prime since the ability to form a memory trace, let alone use it effectively to consciously influence the processing of the target, is highly improbable within such a short period of time (Forster, 1998).

Investigations of morphological processing using masked priming show that stem target recognition is facilitated by morphologically-related primes, but not by purely orthographically-related primes (e.g., Beyersmann, Ziegler, et al., 2016; Rastle, Davis, & New, 2004). For example, the recognition of *CLEAN* is speeded by the prior presentation of *cleaner* relative to an unrelated control prime such as *walker*. Similarly, the recognition of *CORN* is speeded by the prior presentation of *corner*. However, there is no such facilitation for *BROTH* when primed with the non-morphologically related *brothel* (brothel is not morphologically complex as *-el* does not form a suffix in English). This finding has been repeatedly replicated across various Indo-European languages (for reviews, see Amenta & Crepaldi, 2012; Rastle & Davis, 2008), indicating that priming observed in the two morphological conditions is not simply due to orthographic overlap. These data suggest that *cleaner* and *corner* are decomposed into morphemic subunits (*clean+er; corn+er*), thus facilitating responses to the embedded stem targets *CLEAN* and *CORN*. This demonstrates that early in processing, decomposition is based on the appearance of morphology and is insensitive to semantics. This process is referred to as *morpho-orthographic decomposition* (coined by Rastle et al., 2004) and is consistent with the view that a rapid decomposition process is applied to morphologically complex words, in which consequent facilitation of recognising stem targets cannot be ascribed to form overlap.

Masked priming studies using morphologically complex *word* primes have been complemented by studies using similarly complex *nonword* primes. Morphologically complex nonwords are particularly suited for the exploration of early pre-lexical morphological parsing mechanisms because the whole letter string cannot be successfully mapped onto an existing representation in the orthographic lexicon. An initial study by Longtin and Meunier (2005) investigated the lexicality of morpho-orthographic decomposition in a series of masked priming experiments using French items. The authors created three categories of stimuli: syntactically legal affixed pairs (*rapidifier-RAPIDE*); syntactically illegal morphological pairs (*sportation-SPORT*; *-ation* only attaches to verbs); and non-affixed pairs (*rapiduit-RAPIDE*; *–uit* is not a suffix in French). Both types of morphologically-structured nonword primes facilitated the recognition of their stem targets more so than an unrelated baseline. Non-affixed primes (consisting of a stem and a non-morphemic ending), on the other hand, provided no facilitatory effect above baseline. These three effects mirror previous patterns of results with word primes (e.g., Rastle et al., 2004). Longtin and Meunier (2005) therefore concluded that early morpho-orthographic decomposition is indeed insensitive to interpretability and lexicality.

Critically however, several recent studies have failed to replicate the Longtin & Meunier pattern, showing that significant embedded stem priming effects are obtained independently of whether the target is preceded by an affixed nonword (e.g. *flexify-flex*) or a non-affixed nonword (e.g. *flexint-flex*). This finding has replicated across several languages including English (Morris, Porter, Grainger, & Holcomb, 2011), French (Beyersmann, Casalis, Ziegler, & Grainger, 2015; Beyersmann, Cavalli, Casalis, & Colé, 2016; Beyersmann & Grainger, 2017) and German (Hasenäcker, Beyersmann, & Schroeder, 2016); it is also observed in French and German speaking children (Beyersmann, Grainger, Casalis, & Ziegler, 2015; Hasenäcker et al., 2016). Moreover, embedded stem priming effects have been found for stems embedded in both initial and final string position (Beyersmann, Cavalli, et al., 2016), suggesting that the activation of embedded stems is position-independent. These findings are of great relevance to recent theories of morphological processing as they suggest that affix-stripping, which for many years has been believed to be the key mechanism underlying morphological processing, is not sufficient to account for embedded stem priming effects arising in the absence of an affix (e.g. *flexint-flex*). Instead, they suggest that embedded stems are activated independently of morphological structure. These observations have given rise to a novel theoretical account of edge-aligned embedded word processing (Grainger & Beyersmann, 2017). According to this account, word recognition commences with a strictly non-morphological process of activating words embedded at the "edges" of a letter string (i.e. in initial or final string position). That is, embedded stems can be activated without first removing any affixes.

On this theory, the activation of edge-aligned embedded words is particularly successful in the context of complex *nonwords*, because here the whole-letter string is not represented in the lexicon and therefore does not compete with the lexical activation of the embedded word. The reason why embedded stem activation fails in non-affixed *words* such as *cashew* is that the complex word acts as a lexical competitor which inhibits the activation of the embedded word *cash*, thus preventing priming. Of course, competition also arises between pseudo-suffixed words such as *corner* and their embedded stems (*corn*). Here however, the presence of the affix initiates morpho-orthographic decomposition, which boosts the activation of the embedded word, which explains why priming is typically seen in this condition. As discussed in detail by Grainger and Beyersmann (2017), the activation of edge-aligned embedded stems is an entirely non-morphological process. Embedded words are mapped onto pre-existing whole-word representations and can thus be extracted without first removing any affixes.

The present study

The goal of our present study was to further explore embedded stem priming effects in affixed and non-affixed nonwords. Over the last decade, Longtin and Meunier's findings (2005) have been of central importance to theories of morphological processing, suggesting that not only words, but also nonwords are rapidly decomposed into morpho-orthographic subunits during visual word recognition. The recent failures to replicate this finding therefore represent a major challenge to theories of morphological processing, particularly the traditional affix-stripping approach. Our goal was thus to adjudicate between these different findings and carefully examine if significant priming is only obtained if the target is embedded in a morphologically complex nonword prime (e.g., *flexify-flex*; i.e. the Longtin and Meunier pattern) or if it is indeed true that embedded stems are activated independently of whether the stem is accompanied by an affix (e.g. *flexify-flex*) or a non-affix (e.g. *flexint-flex*).

Longtin and Meunier (2005) used different targets for affixed and non-affixed primes, and these targets were not matched on frequency. Because form priming could be more sensitive to target frequency than morphological priming (Longtin, Segui, & Hallé, 2003), the disparity between affixed and non-affixed primes might have been due to a quantitative difference in target frequencies, rather than a qualitative effect of morphological relatedness between primes and targets. A second problem with Longtin and Meunier's (2005) research is that many targets were morphologically complex. Arguably, obtaining masked priming with mono-morphemic targets is of greater importance as it demonstrates that morphological priming can be observed in conditions in which participants have no conscious contact with complex morphological information (Giraudo & Grainger, 2000). It is possible that the exposure to an affixed target would have hindered the activation of the embedded stem, thus biasing participants to use morpho-orthographic segmentation as the optimal processing strategy, which would explain the absence of priming in the non-morphological condition. To avoid these issues in our present study we used the exact same targets across conditions, and all targets were exclusively mono-morphemic.

While several studies have examined embedded stem priming effects in French and German speaking individuals (Beyersmann, Casalis, et al., 2015; Beyersmann, Cavalli, et al., 2016; Beyersmann & Grainger, 2017; Hasenäcker et al., 2016), only two, unfortunately incompatible studies to date have investigated the morphology-independent activation of embedded stems in English (McCormick, Rastle, & Davis, 2009; Morris et al., 2011). Morris et al. 2011 reported statistically equivalent behavioural priming for derived word primes (*flexible-flex*), complex nonword primes (*flexify-flex*) and simplex nonword primes (*flexint-flex*). In contrast, McCormick and colleagues found that complex *but not* simplex nonword primes produce priming to the embedded stem. McCormick et al.'s results thus replicate the Longtin and Meunier pattern, although note that simplex nonword primes did indeed yield a marginally significant priming effect in Experiment 2, suggesting once again that these prior findings are not entirely conclusive.

A further goal of our study was to examine whether or not embedded stem priming effects are position independent. It has been previously shown that embedded stems are activated when embedded in initial as well as in final string position (e.g., Beyersmann, Cavalli, et al., 2016;

Crepaldi, Rastle, Davis, & Lupker, 2013). However, in these previous studies complex nonword primes were semantically non-interpretable stem-affix combinations. There are reasons to assume that semantic interpretability plays a greater role in prefixed words (where the stem occurs in final position) than in suffixed words (where the stem occurs in initial position), because prefixes have an exclusively semantic function, whereas suffixes have both a semantic and syntactic function. Indeed, recent evidence suggests that suffixes are decomposed pre-lexically, whereas prefixes are decomposed post-lexically (Beyersmann, Ziegler, & Grainger, 2015; Kim, Wang, & Taft, 2015). Prefixes may be functioning more like free-standing morphemic constituents than bound morphemes and thus may have a quasi-lexical status compared to the clearly sub-lexical status of suffixes. Hence, semantically transparent prefixed nonwords may generate more priming than semantically transparent suffixed nonwords.

To address these aims, we designed a masked priming study with prefixed and suffixed nonword primes using mono-morphemic targets which were kept constant across conditions. Priming effects were examined under three conditions: (1) when primes were interpretable, that is, sharing a semantically transparent morphological relationship with targets (e.g., *subcheap-CHEAP; cheapize-CHEAP*), (2) when primes were non-affixed, that is, comprising targets and non-affixal letter strings (e.g., *blacheap-CHEAP; cheapstry-CHEAP*), and (3) when real word primes and targets were unrelated (e.g., *miscall-CHEAP; idealism-CHEAP*; control condition). If embedded stems are only activated when accompanied by an affix (Longtin & Meunier, 2005), we would expect priming in the affixed, but not in the non-affixed condition. If however embedded stems are activated independently of morphological status (Beyersmann, Casalis, et al., 2015), we would expect comparable magnitudes of priming in the affixed and non-affixed conditions. Moreover, if semantic interpretability plays a greater role in prefixed than in suffixed letter strings, we would expect that semantically interpretable prefixed nonword primes should facilitate the recognition of their stem targets significantly more than semantically interpretable suffixed nonword primes.

Method

Design

The experiment used a 3x2 mixed design. The independent variables were Prime Type (repeated measures: interpretable affixed nonword vs. non-affixed nonword vs. unrelated word) and Affix Type (between-subjects: prefix vs. suffix). The dependent variable was response time (ms).

Participants

Sixty university students and recent graduates (Age: *M* = 21.45 years, *SD* = 2.13; 58% women) participated in the experiment in exchange for course credit or a £5 payment. All had normal or corrected-to-normal vision and were native speakers of British English.

Materials

Two classes of nonword were created and pretested for semantic plausibility: interpretable affixed and non-affixed nonwords. Interpretable affixed nonwords were formed according to the word formation rules of English. Words such as these often arise in spontaneous speech and in journalistic texts. For example, *coupleness*, from *couple* and *–ness*, and *reupload* from *re-* and *upload* are relatively new but widely used in women's magazines and online blogs respectively even though they are not yet attested in official dictionaries. Interpretable affixed nonwords must be semantically plausible based on the combination of their morphemic constituents. Non-affixed nonwords, on the other hand, were formed from a stem and a non-affixal beginning or ending in English. For example, *cheapstry* is formed from the word *cheap* and the letter string -*stry,* which is not an affix and therefore carries no meaning by itself. The combination of the stem and letter string forms a nonword which is non-morphological and therefore not semantically plausible.

(i) Creation of nonwords. One hundred and fifty stem words were selected from the English Lexicon Project database (Balota et al., 2007) to serve as potential targets. These stems were also used to create the nonword primes. Each stem was selected on the basis that it is a free morpheme but forms part of at least one existing complex English word (e.g., *cheap* was selected because it already forms part of the word *cheaper*). On the basis of Forster and Davis' (1991) density constraint in masked priming lexical decision, all selected stem words also have a low orthographic neighbourhood size (< 5). To create the list of interpretable affixed nonword primes, each stem was combined with a selection of productive prefixes and suffixes. Stem-affix combinations were selected on the basis that they formed nonwords which are phonologically, orthographically, and potentially semantically plausible, which are perfectly parsable into their constituent morphemes (e.g., no deletion of 'e'), and are not entered in the most recent edition of the Oxford English Dictionary. For example, the stem *cheap* generated interpretable affixed nonwords such as *subcheap; overcheap; cheapize; cheapable.*

To create the list of non-affixed nonword primes, each stem was combined with highly frequent letter strings which do not exist as morphemes in the English language. Letter strings were selected by dividing the most frequent mono-morphemic English words (e.g., febr/uary), forming a pseudo-prefix (*febr*) and a pseudo-suffix (*uary*). Stems and letter strings were combined to roughly match the interpretable affixed nonwords in length, and to be phonologically and orthographically plausible. For example, the stem *cheap* formed Non-affixed nonwords such as *betcheap; blacheap; cheapween; cheapstry.*

The resulting 500 nonwords were subject to a pretest to acquire semantic and familiarity ratings. Although all nonwords were formed according to strict grammatical rules for semantic plausibility (and implausibility), a pretest was undertaken so that these objective criteria also matched subjective ratings.

(ii) Pretest. One hundred and sixty-eight native speakers of British English participated in a pretest in order to obtain subjective evaluations of each of the resulting nonwords. None of these participants participated in the main experiment. For each nonword, participants indicated whether the word seemed plausible in English or not on a 1-5 rating scale (1 = not plausible, 5 = very plausible). As noted above, interpretable affixed nonwords can make their way into everyday language use despite not being included in official dictionaries. Hence, in order to provide a stringent test of whether morpho-orthographic decomposition is sensitive to lexicality, participants were also asked to indicate any nonwords that they thought already existed in the English language. Each nonword was rated by at least 9 participants. Participants were a wide range of ages (21-86 years, $M = 42.99$, $SD = 21.14$, 50% women). The 500 items were distributed across eight different lists, ensuring that no more than two nonwords derived from one stem appeared in the same list.

For the final selection of items, interpretable affixed nonwords that had been judged as plausible (at least 3 out of 5) by at least 50% of the participants, and non-affixed nonwords that had been judged as implausible (1 out of 5) by at least 50% of the participants, were retained. Naturally, non-affixed nonwords (e.g. *blacheap*) are semantically implausible, because the embedded stem (*cheap*) and the non-morphemic unit (*bla*) cannot be used to generate a combined meaning. The results of the pretest just confirm the semantic noninterpretability of nonwords in this condition. However, of central relevance to our present study was that *affixed* nonwords in our study formed semantically interpretable stem-affix combinations. The semantic plausibility ratings were used to fine tune the items in the affixed nonword condition. As a result, although all items were nonwords (i.e. they were not listed in the English Lexicon Project database (Balota et al., 2007)), some participants had the sense that certain plausible stem-affix combinations could indeed be real English words, which is why we excluded any items identified by over 50% of the participants as already existing in the English language. A further 12 items were removed so that only one interpretable affixed nonword and one non-affixed nonword from each affix type (prefix, suffix) was formed from each stem. This process resulted in 216 nonwords, based on 54 stems and comprising 54 interpretable prefixed nonwords, 54 interpretable suffixed nonwords, 54 non-prefixed nonwords, and 54 non-suffixed nonwords. The mean plausibility value was 3.46/5 for the prefixed interpretable affixed nonwords (SD = 0.56), 3.42/5 for the suffixed interpretable affixed nonwords (SD = 0.50), 1.29/5 for the non-prefixed nonwords (SD = 0.21), and 1.29/5 for the non-suffixed nonwords (SD = 0.24). As required, there was no significant difference in plausibility between prefixed and suffixed nonwords , but there was a significant difference in plausibility between interpretable affixed and non-affixed nonwords ($F(1, 52) = 2154.31$, $p < .001$, $\eta^2 = .98$). There was no interaction between Affix Type and Prime Type . For each stem target, one prefixed and one suffixed item was selected to act as an unrelated word control prime. All control primes were existing complex words, orthographically, morphologically, and semantically unrelated to targets. Each target was therefore preceded by three prime types in each affix condition.

Insert Table 1 about here

All primes were matched as closely as possible on length, bigram frequency and trigram frequency across Affix Type and Prime Type, while unrelated primes were matched as closely as possible on frequency across Affix Type (descriptive statistics are reported in Table 1). . Targets were the same across Affix Type and Prime Type and were therefore matched perfectly on frequency (*M* = 31.07, *SD* = 53.82) and length (*M* = 4.92, *SD* = 0.70). Interpretable affixed and non-affixed nonword primes do not exist in English and therefore do not have relative frequency counts.

Procedure

The procedure followed Forster and Davis (1984). Nonwords and control words constituted primes, and stems constituted targets. For example, *cheapize* primed its stem *CHEAP*. Primes and targets, forming 324 test pairs (54 targets x 3 prime types x 2 affix types), were split into six experimental lists. In each list, one third of the targets were preceded by an interpretable affixed nonword prime, one third by a non-affixed nonword prime, and one third by an unrelated word control prime. The three lists for each affix type were counterbalanced so that each target was preceded by the three primes across lists but appeared only once in each list. Participants received only one experimental list and therefore participated in all priming conditions, but saw each target only once. Stimuli for this experiment are contained in the appendix.

To minimize the possible influence of strategic factors, the prime-target relatedness proportion was reduced to 33% by adding 54 filler pairs with word targets to each list. Among these, 18 were unrelated word pairs (Prefix: unhappy/BARON; Suffix: equally/BARON), 18 were unrelated interpretable affixed nonword/word pairs (prefix: resnip/EXTRA; suffix: snipable/EXTRA), and 18 were unrelated non-affixed nonword/word pairs (prefix: cridress/SIGH; suffix: dressack/SIGH). To allow participants to make a lexical decision on the word targets, one hundred and eight pairs with nonword targets were also added: 18 orthographically related interpretable affixed nonword/nonword pairs (prefix:

prelaugh/LAURN; suffix: laughless/LAURN), 18 orthographically related non-affixed nonword/nonword pairs (prefix: rafresh/KRISH; suffix: freshod/KRISH), 18 orthographically unrelated interpretable affixed nonword/nonword pairs (prefix: subhorror/GOME; suffix: horrorlike/GOME), 18 orthographically unrelated non-affixed nonword/nonword pairs (prefix: noriron/LIASH; suffix: ironet/LIASH), and 36 orthographically unrelated word/nonword pairs (prefix: replace/BILON; suffix: faceless/BILON). All nonword targets were created by changing one or two letters of an existing word, making sure that the result conformed to the phonotactic constraints of English. In summary, each participant performed a lexical decision on 216 targets (108 words and 108 nonwords). The experiment was preceded by a practice session comprising 10 trials.

Participants were randomly assigned to one of the three experimental lists in the Prefix or Suffix Affix Type condition. They were seated in front of a computer screen (about 50 cm from their eyes). Each trial began with a fixation cross, followed by a 500ms forward mask (#######) the length of the prime. The mask was immediately replaced by the prime, displayed for 47ms. The prime was then immediately replaced by a target which remained on the screen for 3000ms or until a response was made. All primes were in lower case and all targets were in upper case to reduce form overlap. Participants were required to decide as quickly and accurately as possible whether or not each target was an English word. They were not told of the existence of a prime stimulus. Primes and targets were displayed with 14 point Arial font, in black on a white background. Responses were entered via labelled “yes” and “no” buttons on the computer keypad, with participants using the dominant hand for the “yes” (i.e., “word”) response. Participants were instructed to keep their hands on the response keys at all times to encourage quick responding. Stimulus presentation and data recording were controlled by Eprime software, with online randomization of trial order so targets were presented in a different random order for each participant. All experiments were carried out individually, in a quiet room. The total duration of the experiment was 15 minutes.

Whether or not the prime is consciously perceived can be crucial for the nature of the priming effect (Longtin et al., 2003). Therefore, after completing the experiment participants were asked whether or not they could identify the primes. If they answered “yes” participants were asked to give an estimate of the number of trials in which they could identify the prime, and were asked to give examples of the primes they had identified.

Results

Ninety five percent of participants (n = 57) reported that they could not identify the prime stimulus. The remaining three participants reported that they could identify the prime stimulus only occasionally. When asked to name a small number of the primes, participants were incorrect on all occasions. Thus, the identity of the prime was successfully masked.

Response time (RT) data were cleaned following standard practice in the literature. First, only RTs for correct “yes” responses were analysed in the latency analysis. Extremely slow responses (>1500ms) were removed, corresponding to 0.22% of the data. Second, data for one target item - *trust* - were removed from all conditions due to it appearing twice in each list (the second presentation was removed from each list). All participants had an average RT of less than 820ms, and all participants and items had an average error rate of less than 20%. Exploratory data analysis revealed that the remaining RT data were largely normally distributed. The Kolmogorov-Smirnov *D* test for normality yielded a non-significant result for all conditions by items, and a non-significant result for all but one condition by subjects. Namely, the test yielded a significant by-subjects effect for interpretable affixed nonwords in the Prefix condition, $D(30) = .19$, $p = .006$.This result was driven by three slow outliers which fell however well below the most stringent cut-off limit of 1000ms used in masked priming morphology research (see Grainger, Colé, & Segui, 1991). Therefore, all remaining data were subject to confirmatory hypothesis testing.

Mean RTs and error rates are presented in Table 2. Generally, error rates were low, averaging 2.48% across conditions, and therefore not subjected to further analysis in this study The RT data were submitted to by-subject (F_1) and by-item (F_2) analyses of variance (ANOVAs). Affix Type (2 levels: Prefix, Suffix) was a between-subjects factor in subjects analyses and a repeated factor in items analyses; Prime Type (3 levels: affixed, non-affixed, unrelated) was a repeated factor in both analyses. All statistical tests are two-tailed and effects were considered statistically significant if they reached the $p < .05$ level. Mauchley's test for sphericity was non-significant in all RT analyses so no corrections were applied to the data.

Insert Table 2 about here

The main effect of Prime Type was significant ($F_1(2, 116) = 16.99$, $p < .001$, $\eta^2 = .23$; $F_2(2, 104) = 6.67$, $p = .002$, $\eta^2 = .11$). Further investigation of this main effect revealed significantly greater priming ($M = 31.22$ms, $SD = 6.84$) by interpretable affixed nonwords than unrelated words ($t_1(59) = -5.51$, $p < .001$, $r = .58$; $t_2(105) = -4.18$, $p < .001$, $r = .38$). There was also significantly greater priming ($M = 16.45$ms, $SD = 7.91$) by interpretable affixed nonwords than non-affixed nonwords ($t_1(59) = -3.27$, $p = .002$, $r = 0.39$; $t_2(105) = -2.59$, $p = .011$, $r = .25$). There was evidence of more priming ($M = 14.76$ms, $SD = 1.07$) following non-affixed nonwords than unrelated words. This was significant by subjects only ($t_1(59) = -2.66$, $p = .010$, $r = .33$) but the direction of this effect was replicated in the items analysis ($M = 12.34$ms, $SD = 5.47$; $t_2(105) = -1.38$, $p = .172$, $r = .10$). Of note, all significant effects are maintained after the Bonferroni correction for multiple comparisons was applied (a = .05, R = 3, significant p value after Bonferroni correction = 0.017).[1]

There was a main effect of Affix Type, with more priming for prefixed than suffixed items (M = 22.56ms, SD = 1.58). Note that the terms ‘prefixed’ and ‘suffixed’ here also refer to pseudo-prefixation and pseudo-suffixation respectively, relating to the position of the non-affixal letter string in the Non-morphological priming condition. This was significant by items only ($F_1(1, 58) = 1.08$, ns, $\eta^2 = .02$; $F_2(1, 52) = 25.89$, $p < .001$, $\eta^2 = .33$). This main effect should be interpreted with caution. First, a significant effect across items is not the most relevant source of variance for this comparison – a factor that was manipulated between participants. Second, if the main effect of Affix Type was due to differential priming we would expect to see an interaction between Affix Type and Prime Type since RTs in the unrelated condition should not differ between groups. However, the interaction between Prime Type and Affix Type was not significant by subjects ($F_1(2, 116) = 2.47$, ns, $\eta^2 = .04$) or by items ($F_2(2, 104) = 1.25$, ns, $\eta^2 = .02$), suggesting that participants in the prefix condition simply had faster overall response times than participants in the suffix condition. To explore this further the magnitude of priming was calculated across items (i.e., Unrelated –affixed nonword/non-affixed prime). When entered as the dependent variable (and treated as a repeated factor) there was no longer a main effect of Affix Type by items ($F_2(1, 52) = 2.16$, ns, $\eta^2 = .04$) on this difference score, indicating no significant difference in the priming of prefixed and suffixed primes. Importantly however, the main effect of Prime Type was maintained when this difference score was used as the dependent variable ($F_2(1, 52) = 5.42$, $p = .024$, $\eta^2 = .09$).

[1] Seven non-affixed primes mistakenly included a word ending rather than a non-word ending (highlighted with an asterisk in the appendix). We removed these items from the RT analyses, which confirmed significance and direction of the reported results.

Discussion

We investigated the nature of complex word decomposition in visual word processing, using masked priming. Participants made visual lexical decisions to stem targets when these targets were preceded by masked prefixed or suffixed nonword primes. Prime-target relatedness was manipulated in the three ways: (1) primes were interpretable, that is, they shared a semantically transparent morphological relationship with the target (e.g., *subcheap-CHEAP; cheapize-CHEAP*); (2) primes were non-morphological, that is, comprising targets and non-affixal letter strings (e.g., *blacheap-CHEAP; cheapstry-CHEAP*); (3) primes were real, complex words unrelated to the target (e.g., *miscall-CHEAP; idealism-CHEAP*; control condition). These manipulations were chosen to investigate the roles of morphological status (affixed vs. non-affixed), affix class (prefix vs. suffix), stem position (initial vs. end), and semantic transparency in the early stages of visual word recognition, and in decomposition.

The results can be summarised as three main findings. First, both interpretable and non-interpretable primes facilitated the recognition of their stem targets significantly more than when primes and targets were unrelated. Critically, the present results are inconsistent with Longtin and Meunier's (2005; see also McCormick et al., 2009) original findings and therefore challenge the account that embedded stems can only be extracted following the removal of the affix. Instead, our data replicate a pattern that has been repeatedly found in recent nonword priming studies (Beyersmann, Casalis, et al., 2015; Beyersmann, Cavalli, et al., 2016; Hasenäcker et al., 2016; Morris et al., 2011), suggesting that embedded stems are activated independently of whether they are accompanied by an affix (*cheapize-cheap*) or a non-morphemic letter string (*cheapstry-cheap*). Taken together, a clear trend is now evident in the literature showing that embedded stems are activated via an entirely non-morphological process of mapping input strings onto orthographic whole-word representations. Furthermore, embedded stem priming effects have been shown to be modulated by morphological family size (Beyersmann & Grainger, 2017), suggesting that embedded stems are activated to the lexical level, and not just a reflection of lower-level sub-lexical orthographic activation pattern.

How then are the results by Rastle and colleagues (2004) using morphologically complex *word* primes to be reconciled with the present results with morphologically complex *nonword* primes? Rastle et al.'s study (which has been widely replicated since; Amenta & Crepaldi, 2012; Rastle & Davis, 2008) clearly suggests that specialised morpho-orthographic representations of affixes are activated upon presentation of truly suffixed (*cleaner*) or pseudo-suffixed words (*corner*). One possibility is that morpho-orthographic segmentation is particularly important during (pseudo-)complex word processing, helping segmentation when the activation of the embedded stem is hindered. For instance, during the recognition of *corner*, the whole-word *corner* would inhibit the extraction of the embedded word *corn*, which is compensated by the presence of the pseudo-affix *-er*. Such compensation does not arise when the embedded word is followed by a non-affix (e.g., *cash* + *ew*), which is why there is typically no priming reported in this condition. In contrast to words, nonwords such as *flexint* do not lexically compete with the lexical representation of the embedded word *flex*, thus generating priming even in the absence of an affix.

Second, there were no significant differences in the processing of prefixed and suffixed primes, indicating that early morphological processing is not mediated by the position of the stem or by affix class. This finding is consistent with previous results from French-speaking adults (Beyersmann, Cavalli, et al., 2016), suggesting that embedded words are activated independently of whether they are embedded at the beginning or the end of the letter string (see also Crepaldi et al., 2013). Indeed, Grainger and Beyersmann (2017) edge-aligned embedded word theory suggests that the spaces surrounding written words provide privileged anchor points for orthographic processing. The activation of embedded words is facilitated by the marking of word boundaries by spaces between words (see also Fischer-Baum, Charny, & McCloskey, 2011, for a related proposal of the "both-edges" coding scheme), and thus applies to words embedded in both initial and final position of the string.

The absence of a position effect seems to be in contrast with the hypothesis that semantic transparency effects may be particularly pronounced in prefixed letter strings, which have a purely semantic function, and therefore would be expected to generate more priming than suffixed letter strings. However, the present robust embedded stem priming effects point to a secondary role of affix-processing during the initial stages of complex nonword processing. It is therefore possible that a difference between prefixed and suffixed nonwords arises at slightly later processing stages, perhaps when the reading system attempts to compute a meaning for novel stem-affix combinations (see for instance Meunier & Longtin, 2007, who report evidence for semantic interpretability effects of complex nonwords in cross-modal priming). Testing these claims using partly or fully visible primes in future research may provide a clearer picture of the proposed multiple stages of visual word processing and the morphological characteristics by which they are affected.

Third, interpretable affixed primes facilitated the recognition of their stem targets more than non-affixed primes. The obvious explanation for this finding is that the activation of the interpretable affix facilitates embedded stem activation. This result provides an important extension of previous nonword priming studies in which comparable magnitudes of priming were observed for non-interpretable affixed and non-affixed nonword primes (e.g., Beyersmann, Casalis, et al., 2015; Beyersmann, Cavalli, et al., 2016; Morris et al., 2011). One reason why these studies might have failed to find a difference in priming between affixed and non-affixed nonwords is that affixed nonwords were semantically non-interpretable (Beyersmann, Casalis, et al., 2015; Beyersmann, Cavalli, et al., 2016;

Hasenäcker et al., 2016; Morris et al., 2011). Clearly, semantics must exert some effect on complex nonword recognition, otherwise, how could we understand a novel word such as *misunderestimated*?

The obvious advantage of interpretable relative to non-interpretable complex novel words is that interpretable stem-affix combinations generate meaning, whereas non-interpretable stem-affix combinations do not. The representation of the interpretable affix (e.g. *–ize* in *cheapize*) may boost the activation of the embedded stem (*cheap*) when the reading system attempts to 're-combine' stem and affix (*cheap + ize*) in order to compute a meaning for the novel input letter string. Such a licensing mechanism has previously been proposed by Schreuder and Baayen (1995) and can account for the increased magnitude of priming obtained with interpretable affixed nonword primes. The licencing of non-affixed letter strings however is unsuccessful (e.g. *cheap + stry* form neither a syntactically nor a semantically interpretable unit) and therefore explains the reduced priming effect in this condition. Consistent with this hypothesis, Meunier and Longtin (2007) reported increased cross-modal priming effects for semantically interpretable compared to non-interpretable complex nonword primes (for converging evidence, see also Burani, Dovetto, Spuntarelli, & Thornton, 1999; Coolen, van Jaarsveld, & Schreuder, 1991; Wurm, 2000).

What is less clear is how early exactly semantics can influence morphological processing, a question which has been hotly debated for many years (e.g., Feldman, O'Connor, & Moscoso del Prado Martin, 2009; Rastle & Davis, 2008). Several masked priming studies have revealed equivalent priming for semantically transparent (e.g. *farmer-FARM*) and semantically opaque complex words (e.g., *corner-CORN*), suggesting that the initial stages of morphological processing are insensitive to semantics (for reviews, see Amenta & Crepaldi, 2012; Rastle & Davis, 2008). This claim is also supported by Longtin and Meunier's (2005) masked priming study, which reported equivalent magnitudes of masked priming for semantically interpretable and non-interpretable nonwords (importantly however, there are methodological problems with this study, as outlined in our Introduction). Other studies however speak in favour of the important role of semantics during morphological processing. Particularly compelling evidence, for instance, comes from a recent masked priming study by Jared, Jouravlev, and Joanisse (2017), who revealed graded priming effects with 50ms SOAs with the largest effect for transparent (*foolish-fool*), the second largest for quasi-transparent (*bookish-book*), and the smallest for opaque complex words (*vanish-van*). This behavioural pattern was replicated in data from event-related potentials, suggesting that semantics play an important role during the early stages of morphological processing. Critically, Jared et al.'s findings are not necessarily inconsistent with the hypothesis that visual word input initially undergoes a semantically blind morpho-orthographic analysis: early influences of semantics can be accounted for by feedback connections between post-lexical morpho-semantic representations and pre-lexical morpho-orthographic representations (as for instance in the hybrid model proposed by Diependaele, Sandra, & Grainger, 2009). The time course and interplay of semantic and morphological processing will certainly continue to be in the centre of debate of future research.

Conclusions

In summary, the current research points to the early activation of embedded stems in visual word processing. This process is seemingly applied to all nonwords consisting of stem + affix or stem + non-affix, irrespective of the position of the stem. Our findings thus provide an important extension of morphological processing theories, suggesting that affix-stripping alone is not sufficient to account for our data. The present findings support a recent trend in the literature showing that embedded stems are activated via an entirely non-morphological process of mapping input strings onto orthographic whole-word representations. In addition, our findings suggest that embedded stem activation is boosted when stem and affix form a semantically interpretable letter string, presumably because the reading system uses semantic licensing based on the morphological sub-components to compute a meaning for the novel letter string.

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Table 1

Table 1. Mean length and logarithmic frequencies for primes in both prefixed and suffixed conditions, as extracted from the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993). Standard deviations are reported in parentheses. Examples of primes correspond to target CHEAP.

	prefixed			**suffixed**		
property	**affixed**	**non-affixed**	**unrelated**	**affixed**	**non-affixed**	**unrelated**
example	*subcheap*	*blacheap*	*miscall*	*cheapize*	*cheapstry*	*idealism*
number of letters	8.11 (1.09)	8.21 (1.10)	8.11 (1.09)	8.30 (1.05)	8.38 (1.00)	8.28 (1.04)
bigram frequency	9.86 (0.36)	9.80 (0.41)	9.98 (0.31)	9.91 (0.45)	9.87 (0.44)	9.92 (0.50)
trigram frequency	3.16 (0.27)	3.15 (0.27)	3.27 (0.27)	3.33 (0.31)	3.17 (0.30)	3.40 (0.29)
word frequency	0.00 (0.00)	0.00 (0.00)	0.19 (0.35)	0.00 (0.00)	0.00 (0.00)	0.39 (0.49)

Table 2

Table 2. Error rates and reaction times across Prime Type and Affix Type. Standard deviations are reported in parentheses.

	Prime	**Errors (%)**	**Reaction Times (ms)**
prefixed	affixed	3.39 (0.06)	599 (88)
	non-affixed	3.56 (0.04)	609 (91)
	unrelated	2.67 (0.05)	619 (87)
suffixed	affixed	1.11 (0.04)	621 (87)
	non-affixed	1.14 (0.04)	636 (98)
	unrelated	3.02 (0.04)	651 (90)

Appendix

Complete list of prime (columns 1-6) and target stimuli (last column).

prefixed			suffixed			
affixed	**non-affixed**	**unrelated**	**affixed**	**non-affixed**	**unrelated**	**target**
misabort	secabort	befriend	abortism	abortlem	cynicism	ABORT
nonabrupt	*betabrupt	oversleep	abruptish	abruptort	blandness	ABRUPT
nonacid	mesacid	recheck	acidness	acidinst	lockable	ACID
nonadept	febradept	misplace	adeptally	*adeptbe	frameable	ADEPT
misadopt	langadopt	microjet	adoptful	adoptonse	fruitful	ADOPT
overagree	contagree	discredit	agreeful	agreestry	dateless	AGREE
overair	suppair	bedevil	airlike	airnst	boaster	AIR
misalarm	secalarm	reconvict	alarmable	alarmonse	plentiful	ALARM
overalert	probalert	nonsense	alertable	alertonse	blindness	ALERT
subangel	suppangel	bioagent	angelness	angeluary	breakable	ANGEL
debeast	wobeast	misdeed	beaster	*beastbe	careful	BEAST
deblaze	fiblaze	redress	blazeless	*blazebe	crispness	BLAZE
prebliss	chabliss	disagree	blissless	blissould	clothless	BLISS
reblock	arblock	preheat	blockist	blockond	feverish	BLOCK
reblood	agablood	preshow	bloodship	blooduage	electable	BLOOD
semiblunt	contblunt	demystify	bluntish	bluntard	ruralism	BLUNT
overbraid	magabraid	reapprove	braidable	*braidcult	absurdism	BRAID
misbreak	dribreak	overlord	breakless	breakuage	guitarist	BREAK
polybulb	stabulb	redirect	bulber	bulblem	artful	BULB
subcheap	blacheap	misguage	cheapize	cheapstry	idealism	CHEAP
dechief	archief	misword	chiefism	chiefrol	absently	CHIEF
dechill	thichill	reenact	chillable	chillonse	abusively	CHILL
biocircle	chacircle	refurbish	circleless	circlezine	respectful	CIRCLE
outclaim	woclaim	distress	claimy	claimve	eyeful	CLAIM
declue	liclue	rebook	clueable	clueree	doubtful	CLUE
intracoast	matercoast	disconnect	coastable	coastuage	serialism	COAST
subcorrect	agacorrect	dishearten	correctist	correctinue	changeable	CORRECT
nondevil	bladevil	disorder	devilship	devilonse	formalist	DEVIL
overdirect	thoudirect	disgruntle	directist	directonse	regardful	DIRECT
polyevent	probevent	disbelief	eventize	eventond	hairlike	EVENT
semifact	chafact	belittle	factism	factlem	bathful	FACT
outfather	blafather	redeliver	fatherness	fatherinue	breathless	FATHER
biofever	blafever	overgrow	feverize	feverange	actually	FEVER
nonfirm	stafirm	subzero	firmity	firmtry	warlike	FIRM
beflower	eiflower	microcar	flowerize	flowernge	shameless	FLOWER
antifluid	agafluid	microchip	fluidation	fluidond	ironically	FLUID
defoam	materfoam	rehire	foamable	foamough	childish	FOAM

overfrank	thoufrank	subwoofer	frankful	frankonse	walkable	FRANK
underfrill	secfrill	semicircle	frillable	frillould	treatable	FRILL
overgross	indugross	overtired	grossable	grossinst	adversely	GROSS
disgrudge	thougrudge	misadvise	grudgeful	grudgelem	formalism	GRUDGE
reguard	diffiguard	overlap	guardism	guardlem	chewable	GUARD
overhelp	conthelp	misdealt	helpy	*helpbe	aptly	HELP
bioherb	secherb	miscall	herbish	herbstry	sadness	HERB
subhero	whihero	preread	herolike	herotter	finalist	HERO
demarsh	fimarsh	unalike	marshable	marshuage	equalness	MARSH
derich	worich	misaim	richish	richinue	braless	RICH
deslave	eislave	overarm	slaveism	slaveort	growable	SLAVE
polytangle	langtangle	overcommit	tangley	*tanglebe	gleeful	TANGLE
polytitle	drititle	disrepair	titleless	titleuary	shapeless	TITLE
overtrust	matertrust	misbehave	trustship	truststry	avoidable	TRUST
semivalid	probvalid	overdraft	validize	validlem	wasteful	VALID
superverb	induverb	nonactive	verblike	verbinue	lockable	VERB

* The embedded target was combined with a real word unit instead of a non-affix.