A Ton of Planks in *Plankton*: Examining Morpho-Orthographic Decomposition in the Early Stages of Complex Word Processing

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Abstract

The processing of morphologically complex words is a matter of continued interest and debate in the field of linguistics. Recent research has provided increasing evidence that words are morphologically decomposed during visual word recognition; however, precisely when morphemes are activated during the time course of word recognition, and which word types undergo morphological decomposition remain a matter of debate. The extent to which the process of morphological decomposition interacts with and is modulated by semantic relationships, orthography, lexical status, first or second language, and experimental conditions (such as modality of stimulus presentation) is relevant to current research. The current study seeks to investigate the effects of semantic transparency, orthographic overlap, and morphological status in the mental lexicon (i.e. whether a word is argued to have a morphologically complex representation in the mental lexicon, such as “walking”, or a monomorphemic one, such as “corner”) on morphological decomposition in compound words. This is performed by comparing behavioral responses (within the context of a lexical decision task using the masked priming paradigm) for semantically transparent compound words (e.g. “teacup”), semantically opaque compound words (e.g. “honeymoon”), monomorphemic real words that contain an orthographically overlapping pseudomorpheme (e.g. “flamenco”, which begins with “flame”), and real word “false compounds”: monomorphemic pseudocompounds (e.g. “plankton”) that can be exhaustively parsed into two constituent pseudomorphemes on the basis of orthography (in this case, “plank” and “ton”). This study replicates and extends the study by Fiorentino & Fund-Reznicek (2009), which found significant and equivalent priming effects for both transparent and opaque compounds in comparison to unrelated primes, but no effects for

the orthographically overlapping primes; by additionally testing responses to false compounds, this study is able to examine the extent to which semantic transparency in combination with morphological status in the lexicon interact with morphological decomposition in the absence of affixation.

We find that the priming effect of such false compounds is statistically equivalent to that of both transparent and opaque compounds, but dissociates from that in the orthographically overlapping pseudomorpheme condition. The results of this study replicate the findings of Fiorentino & Fund-Reznicek (2009) for transparent and opaque compounds, and extend the findings of Rastle et al. (2004), which found significant and equivalent priming effects for both semantically transparent suffixed words (e.g. “cleaner”) and semantically opaque monomorphemic pseudosuffixed words (e.g. “corner”) in comparison to unrelated primes, but no effects for orthographically overlapping primes (e.g. “brothel”, which begins with “broth”), to false compounds. These findings indicate that morphological segmentation applies to the appearance of morphological structure on an orthographic basis, and does so even when no apparent affixation is present, supporting an account of morphological processing that involves early and automatic across-the-board morpho-orthographic decomposition.

Introduction

Interest in the nature of complex words (e.g. "walked") has stimulated research of the topic for decades, resulting in several competing theories and models attempting to explain their representation and processing in the brain/mind; these theories have particularly focused on morphological structure, to what degree such structure is processed, and how morphological processing is manifested (for a recent review regarding morphological processing in the visual modality see Amenta & Crepaldi 2012). One general approach proposes that morphological structure is not representative of what is actually processed in the mind, and so complex words are not morphologically decomposed at all, but rather processed as single units. This perspective notes that pairs of words are related to each other in form and meaning (e.g., "walked" and "walk" are similar in meaning and in orthographic/phonological form), and attributes behavioral results that reflect relationships between complex words and constituents to interactions resulting from these form and meaning relationships (e.g., Bybee 1995, which assumes that the representations of related words in the mental lexicon become associated with each other through repeated experience). A non-decompositional view of complex word processing may also be implemented in connectionist models that attempt to account for behavioral interactions between word pairs based on the nature and degree of their relatedness in sublexical form or meaning units (e.g., Seidenberg & Gonnerman 2000, which assumes that relationships typically analyzed as being between whole words and constituent morphemes are instead formed on the basis of shared activation of orthographic or meaning units).

Another general approach proposes that complex words are processed by way of morphological decomposition. This perspective notes that while word pairs such as "unlock" and “lock” are related to each other both semantically as well as in form, critically, that relationship is morphological in nature, manifested not merely by semantic or orthographic overlap, but by morphological identity: The two words share a morpheme. Likewise, while word pairs such as “taught” and “teach” are related in meaning, they both bear the same root morpheme, even if the surface form has undergone transformation due to an irregular process (Stockall & Marantz 2006).

Within the decompositional view, multiple models and factors must be taken into consideration. In addition to lexical and form properties like word and morpheme frequency, word and morpheme length, and phonological/orthographic neighborhood impacting word processing in general, factors that have been proposed as impacting the morphological decomposition of complex words in this view include semantic transparency, lexical status, experimental modality and subconscious versus conscious processing. A sublexical model (Stockall & Marantz 2006) posits that words are decomposed into smaller parts as an initial parsing process, putting forth morphological decomposition as an early, automatic and principal part of the processing of words (e.g. a morphologically complex word like “unlock” must first be broken down into the prefix “un-” and root “lock” during the initial stages of processing). Additionally, a sublexical view of morphological decomposition that considers the process unmodulated by semantic transparency would expect semantically opaque compounds like “honeymoon” to be decomposed in the same manner as semantically transparent words like “unlock” and “teacup”. As a result, in comparison to meaningfully and lexically related word pairs like “unlock” and “lock” or “teacup” and “tea”, such a sublexical view would anticipate comparable measured behavioral effects for word pairs like “honeymoon” and “moon” (a semantically opaque compound and one of its constituents), such as those found in Fiorentino &

Fund-Reznicek (2009). (Note that, under a sublexical view, while the factors mentioned above are not taken to preclude decomposition, they may still impact post-decompositional, compositional processing – see EEG evidence of this, for example, in Fiorentino et al. 2014.)

A supralexical model (Diependaele, Sandra & Grainger 2005) posits that whole word access must occur first, prior to morphological decomposition. While this view still puts forth morphological decomposition as automatic and underlying behavioral effects found across regular and semantically related word pairs, it places morphological decomposition potentially as a much later process. For example, the results of Giraudo & Grainger (2001) found that, while morphologically related prime and target word pairs showed greater priming effects than unrelated word pairs, for morphologically complex related targets, root primes showed no greater effects on reaction times than complex primes; as they postulated that early morphological decomposition of complex words should entail an early parsing step that simple roots do not need, they concluded that the lack of difference between priming effects supports a view of morphological decomposition as a process preceded by whole word access. Additionally, a supralexical view of morphological decomposition that considers the process modulated by semantic transparency or lexical status would expect a semantically opaque compound word like "honeymoon" to be processed differently from semantically transparent words, and would in turn anticipate relatively reduced or null behavioral effects for word pairs like "honeymoon" and "moon" in comparison to those found for meaningfully and lexically related word pairs.

Along with the supralexical model, there are additional "dual-route" models of complex word processing that propose an integration of both morphological decomposition and whole word access. The Morphological Race Model (Frauenfelder & Schreuder 1992) and similar models propose that both morphological decomposition and whole word access are used as processing strategies simultaneously in complex word processing. The strategy that is ultimately expected to be used in the model is determined on a word-by-word basis, depending on which is most likely to be faster, as a result of which lexical and morphemic properties are most facilitative, such as whole word frequency or semantic transparency. Alternatively, the Words and Rules model proposed by Pinker (1999) and Pinker & Ullman (2002) posits that regular complex words are decomposed by rule, but irregular ones are memorized, overlapping both views in a manner dependent upon morphological regularity: While some complex words in this model must be memorized, a fully non-decompositional approach is insufficient to account for words that are derived as a result of regular morphological rules.

Masked Priming

Masked priming has become a primary method for investigating processing of complex words in the recent literature, especially to test if and when morphological decomposition occurs. Masked priming (Forster & Davis 1984) involves the presentation of a forward "mask" (typically presented as a series of hash marks, equivalent in number to the number of letters in the upcoming prime) that precedes a briefly presented prime. The duration of this presentation, the stimulus-onset asynchrony (SOA) can be varied widely, but is typically under 60 ms as that is brief enough for participants to remain unaware of the prime's presence.

Following the prime, the target word is presented (sometimes with a "backward mask" interspersed briefly between the two), and, in most tasks (such as a lexical decision task), the participant presses a button for one of two options in response to the target word, and the experiment proceeds to the next trial. By presenting a prime for a sufficiently short period of time, early and automatic aspects of visual word processing commence, but later, conscious processes are avoided. This enables activation of the initial subconscious stages of complex word processing, and tests the primacy of morphology, orthography and semantics in such processing.

Rastle et al. (2004) examined the processing of complex words using masked priming by comparing responses to three sets of suffixed prime and root target word pairs: pairs with a semantically transparent morphological relationship (e.g. "cleaner" and "clean"), pairs with a semantically opaque, apparent morphological relationship (based upon orthography or etymology; e.g. "corner" and corn", or "department" and "depart") and pairs with an orthographic overlap only (e.g. "brothel" and "broth"). The goal of the study was to examine morphological decomposition in complex word processing through the lens of semantic information: specifically, to what extent visual word recognition involves an early morpho-orthographic segmentation process that is blind to semantics. While past results using cross-modal or non-masked visual priming paradigms have shown effects of semantic transparency in the processing of morphologically related complex words (e.g. Marslen-Wilson et al. 1994), effects of semantic relatedness have failed to emerge in the context of masked priming (e.g. Rastle et al. 2000, which found effects of semantic relatedness for a longer, non-masked SOA of 230 ms, but no such effects with a SOA of 43 ms), suggestive of a difference in timing that could reflect multiple stages of complex word processing. As a result Rastle et al. (2004) utilized a lexical decision task with a sufficiently short SOA of 42 ms; participants viewed a forward mask for 500 ms followed by the prime in lower case letters and then the corresponding target in upper case letters until they made a decision as to the lexicality of the target.

Rastle et al. (2004) found significant and equivalent priming effects for both the semantically transparent and semantically opaque conditions, but no priming effects for the orthographic overlap condition. These equivalent priming effects for both the semantically transparent and opaque conditions indicate that semantic relationships are insufficient to account for early morphological decomposition (cf. Feldman et al. 2009; see Davis & Rastle 2010 for further discussion); moreover, the lack of priming effects in the orthographic overlap condition indicate that form overlap alone is also insufficient. Given that the words in the semantically opaque condition were not necessarily morphologically related, the results overall support complex word processing as involving an early, subconscious segmentation process that operates on the appearance of morphology within words (i.e., whenever a word, like “corner”, can be exhaustively parsed into orthographic forms that match those of existing morphemes, like “corn” and “-er”), overall supporting decompositional views of complex word processing. This early process of morphological decomposition was characterized by Rastle et al. (2004) as obligatory, consistent with the conclusions drawn by Taft & Forster (1975) that affixed words are readily recognized as such and “stripped” of their affixes due to the high-frequency and short-form nature of affixes, and determined, in the visual modality, by orthography. The results of Rastle et al. (2004) were replicated by McCormick et al. (2008) with suffixed prime words that undergo regular orthographic changes in the context of morphology (such as the semantically transparent “metallic”, which possesses a duplicated “l” not found in its constituent morphemes “metal” and “-ic”) and corresponding semantically opaque monomorphemic prime words (such as “badger”, which appears to possess a stem “badge” and suffix “-er” with a single shared “e”), suggesting that this process is highly robust, even in the context of common orthographic conventions.

Similarly, Fiorentino & Fund-Reznicek (2009) also examined the processing of complex words using masked priming, specifically with compound words. The responses to three sets of compound prime and root target word pairs were compared: pairs with a semantically transparent relationship (e.g. “teacup” and “cup”), pairs with a semantically opaque relationship (e.g. “honeymoon” and “moon”) and pairs with an orthographic overlap only (e.g. “battalion” and “lion”). The study sought to examine the nature of morphological decomposition in complex words by testing to see if effects found in previous studies (such as Rastle et al. 2004) were restricted to complex words containing affixes, or would likewise emerge in multi-stem, compound words.

This test of the nature of morphological decomposition is an important one. The findings of Rastle et al. (2004) can be accounted for by a view in which decomposition is reliant upon the presence of closed-class affixes rather than morphological structure in general. However, finding masked priming effects for compound constituents that indicate morphological decomposition would warrant a view in which early stages of word processing are attuned to morpheme-level representations at large, without restriction to a subset, such as closed-class affixes. Additionally, while Rastle et al. (2004) was only able to test targets that were word-initial stems within their related primes, Fiorentino & Fund-Reznicek (2009) faced no such limitation with compound words. Two experiments were conducted, one testing targets that were in the word-initial, non-head position of related primes, another testing targets that were in the word-final, head position of related primes. This enabled the study to test for effects of priming by position and importantly, since the impact of semantic relatedness in morphological decomposition is of ongoing interest, for effects of priming by headedness. Both experiments in Fiorentino & Fund-Reznicek (2009) were also lexical decision tasks, with a SOA of 50 ms; participants viewed a forward mask for 500 ms followed by the prime in lower case letters and then the corresponding target in upper case letters until they made a decision as to the lexicality of the target.

The results found by Fiorentino & Fund-Reznicek (2009) were in line with those of Rastle et al. (2004): in both experiments, semantically transparent and opaque compound words fully and equivalently primed their constituents in comparison to unrelated primes, while no priming effects were found for orthographically related word pairs. These equivalent priming effects for both the semantically transparent and opaque compound primes further demonstrate that semantic relationships are insufficient to account for early morphological decomposition, while the lack of priming effects in the orthographic overlap condition again demonstrate that form overlap alone is insufficient. Based on the priming effects by condition across both experiments, no positional (morphologically or orthographically speaking) or headedness effects were found. The similarity in priming effects by condition across both Fiorentino & Fund-Reznicek (2009) and Rastle et al. (2004) indicates that complex word processing treats compound words and affixed words similarly; morphological decomposition does not necessitate the presence of short, high-frequency affixes or inflection. The results from the two studies support the conclusion that, since both semantically opaque monomorphemic words like “corner” and semantically opaque compounds like “honeymoon” prime their targets in the absence of semantic relatedness and in a manner attributable not to shared orthographic form, early stages of complex word processing involve automatic decomposition that is dependent upon, at minimum, the appearance of morphology (see also Li et al. 2015, which provides converging evidence of such decomposition in English by advanced Chinese-speaking learners).

The overall view of morphological decomposition that is supported by the results of Rastle et al. (2004) and Fiorentino & Fund-Reznicek (2009) is one of a process that is early, automatic and occurs in an across-the board manner on a morpho-orthographic basis. This most closely supports a sublexical model of morphological decomposition, given the primacy of segmentation, and lack of early semantic transparency effects to implicate full word lexical access. In fact, the results of Rastle et al. (2004) suggest that the nature of sublexical morphological decomposition may apply to even monomorphemic words in early complex word processing provided that the word bears the appearance of morphological structure.

Current study

The results of Fiorentino & Fund-Reznicek (2009) provide support for a view of complex word processing that allows for across-the-board morphological decomposition, unmodulated by semantic transparency, unaffected by word-initial or word-final (non-head/head) positioning of constituents, and without the need for facilitation by the presence of an affix. The significant and equivalent priming effects for both semantically transparent and semantically opaque compound words is a finding that would not be predicted by dual route models positing morphological segmentation only for complex words that bear semantically transparent relationships with their constituents, which would anticipate such words to be processed differently by the mind. Additionally, this finding in combination with the lack of priming effects for orthographically overlapping prime and target word pairs would not be predicted by non-decompositional models, which would anticipate correlations in priming based on form and/or meaning, but not based on morphology.

There is a notable difference in stimuli between Fiorentino & Fund-Reznicek (2009) and Rastle et al. (2004), however: The semantically opaque condition of Fiorentino & Fund-Reznicek (2009) used compound words like "honeymoon" as primes, which are not only able to be orthographically segmented into potential morphemes ("honey" and "moon"), but are also argued in some theoretical approaches to indeed be morphologically complex words, with these morphemes as constituents. On the other hand, the semantically opaque condition of Rastle et al. (2004) used a mix of apparently suffixed words based upon etymology like "department" alongside pseudo-suffixed words like "corner", which appear morphologically complex, but are not assumed to actually be morphologically complex words. This raises the question of whether the two studies reflect two separate effects or one held in common: whether semantically opaque primes in Fiorentino & Fund-Reznicek (2009) show evidence of being decomposed into constituents due to actual morphological structure, while semantically opaque primes in studies like Rastle et al. (2004) show evidence of being decomposed into merely apparent constituents due to affix stripping, or whether both kinds of semantically opaque primes are decomposed as a result of an across-the-board morpho-orthographic process.

In order to continue to explore the extent to which morphological decomposition applies in an across-the-board manner in the processing of complex words, the present study mimics Fiorentino & Fund-Reznicek (2009) in the main, but adds a new condition: "false compounds". False compounds are semantically opaque pseudocompounds that, along the lines of pseudoaffixed words like "corner", can be exhaustively parsed into two apparent pseudomorphemes on the basis of orthography. For example, "plankton", can be broken down into "plank" and "ton" on the basis of apparent morphological structure due to a coincidence of orthography, but underlyingly has no semantic or morphological (or etymological) relationship.

By mirroring the morpho-orthographic character of the pseudo-suffixed words in the semantically opaque condition in Rastle et al. (2004), the comparison between the priming effects of false compounds like “plankton” to semantically opaque compounds like “honeymoon” will allow for a more precise refinement of models of complex word processing, especially in the early and automatic phases. This supports testing priming effects for the specific features of the false compound condition in a masked priming paradigm, given that the results of Rastle et al. (2004) showed priming effects for pseudo-suffixed words in the semantically opaque condition while the results of Fiorentino & Fund-Reznicek (2009) confirmed priming effects in compound words that parallel those of suffixed words. Not only are false compounds semantically opaque, they do not bear a morphological relationship to their apparent constituents (which differentiates them from semantically opaque compounds like “honeymoon”), nor do they bear an apparent high-frequency, typically productive affix (differentiating them from pseudo-suffixed words like “corner”).

If false compound primes elicit priming effects that are significant and comparable to those of actual compound word primes, evidence for across-the-board morphological decomposition will be further reinforced: Along with being semantically opaque and analyzed as underlyingly monomorphemic in the lexicon, false compounds also lack any appearance of affixation; across-the-board morpho-orthographic decomposition as an early and automatic process on the basis of the appearance of morphological constituency (at a subconscious level) would be evidenced, regardless of affixation or constituent position, and in alignment with a sublexical approach.

If, however, false compound primes elicit reduced or no priming effects, some measure of modulation in early morphological decomposition will be suggested. In this instance, semantic opacity cannot be the determining factor, since semantically opaque compounds are expected to show full priming as in Fiorentino & Fund-Reznicek (2009). Instead, morphological status and a lack of affixation are likely factors, suggesting that facilitation by affixation is sufficient for priming effects in monomorphemic pseudoaffixed words in studies like Rastle et al. (2004), but in the absence of affixation, mere appearance of morphological constituency is insufficient.

Method

The experiment reported in this paper is based upon Experiment 1 from Fiorentino & Fund-Reznicek (2009), in which the priming of word-initial (non-head, where applicable) constituents is tested. The three test conditions of Fiorentino & Fund-Reznicek (2009) were retained, and a fourth condition testing false compounds was added.

Stimuli

In the transparent compound condition, compound words that are relatively transparent in meaning (e.g. “teacup”) were used as masked primes for their constituents. In the opaque compound condition, compound words that are relatively opaque in meaning (e.g. “honeymoon”) were used as masked primes instead; the measure of whether a compound used in this study is transparent or opaque relative to its constituents was based on the rating study reported in Fiorentino & Fund-Reznicek (2009). In the orthographic overlap condition, monomorphemic words that have the appearance of beginning with another monomorphemic word were used as masked primes for their apparent constituent (e.g. “gazelle” begins with the same letters as “gaze”); the remaining letters in the prime, however, do not form a morpheme in English. In the false compound condition, however, words that have the appearance of being composed of two smaller, monomorphemic words but are in fact monomorphemic themselves (e.g. “asphalt” appears to be made from “asp” and “halt”) were used as masked primes for their apparent constituents; the relationship between monomorphemic prime and apparent constituent target in both this and the orthographic overlap condition is necessarily semantically opaque. Examples of prime and target stimuli are shown in Table 1:

Table 1: Examples of primes and targets for each condition within the experiment

Condition	**Prime**	**Target (non-head)**
Transparent compound	drainpipe	drain
Opaque compound	hallmark	hall
Orthographic overlap	flamenco	flame
False compound	plankton	plank

Each of the four conditions contained 16 prime-target pairs. Each of the related prime-target pairs (for example, “drainpipe” and “drain”) had a corresponding unrelated control pair (in this case, “stopwatch” and “drain”) in which the target was the same and the unrelated prime was still a word of the same morpho-semantic type (e.g. for targets in the opaque compound condition, both related and unrelated primes were semantically opaque compound words). These related and unrelated primes were matched overall for length, within-condition ($p > 0.718$, all conditions). Both related and unrelated primes were also matched for log frequency, within condition ($p > 0.533$, all conditions).

The following factors were also controlled across conditions: length of unrelated prime ($p > 0.073$, all conditions); log frequency of related prime, unrelated prime, and target ($p > 0.204$, all conditions); proportion of target length to prime length ($p > 0.495$, all conditions); length of target ($p > 0.191$, all conditions); and orthographic neighborhood of related prime and target ($p > .066$, all conditions). The log frequency measures used were taken from the SUBTLEXus corpus (Brysbaert & New 2009).

The following factors were controlled across conditions when possible, with one exception for each: length of related prime ($p = 0.04996$ transparent compound vs. false compound conditions; $p > 0.135$ otherwise) and orthographic neighborhood of unrelated prime ($p = .01395$ opaque compound vs. orthographic overlap conditions; $p > .072$ otherwise).

Two additional factors were coded, but not controlled. The factor “phonological change” indicated that the pronunciation of the target differed from the pronunciation of the corresponding portion of the prime that overlapped orthographically with the target (e.g., compare the first consonant in "champagne" with that of its target "champ"). The factor “vowel reduction” indicated that the pronunciation of the prime contained vowel reduction that would not be expected if the word was a compound. For example, the second vowel in "bargain" is reduced, but the vowel in “gain” is not, so the prime “bargain” was coded for vowel reduction. Compare this to the word “mandate”, which does not contain vowel reduction: The pronunciation is identical to how the word would be pronounced if it were a novel transparent compound referring to a date between men. Note that the compound word “mastermind” would not be coded for vowel reduction either, as the vowel reduction present in the word is the same vowel reduction found in the initial/non-head target constituent “master”. Since these factors are not present in actual compound words, they were coded when present in the orthographic overlap and false compound conditions in order to see if there are any measureable interactions between the phonological form of a word and its processing in the visual modality. One might wonder if, for example, the presence of a phonological form not found in compound words might show reduced effects of morphological decomposition.

Stimuli in the transparent compound, opaque compound, and false compound conditions were selected to ensure that none of the related primes could be parsed in multiple ways (e.g., “beanstalk” was excluded on the basis that it can be parsed as both “bean” plus “stalk” and “beans” plus “talk”). If it is true that such parsing occurs automatically, it should be avoided in the related primes to prevent any potential confounds. Stimuli in the orthographic overlap condition that could be parsed for multiple word-initial or word-final apparent morphemes (e.g., “paternity” begins with both “pat” and “pate”) were coded as such, in case it influenced the results.

Stimuli in the orthographic overlap and false compound conditions were checked for their etymology using the Online Etymology Dictionary (www.etymolonline.com). Since the prime-target pairs in these two conditions must be completely unrelated except for orthographic overlap in the related pairs, words that could be confounded as being multimorphemic due to their etymological origin were excluded (for example, “sirloin” was discarded as a potential stimulus due to its origin as “sur-” plus “loine”).

In addition, 64 real word prime – nonword target pairs were constructed. The real word primes consisted of 16 each of transparent compounds, opaque compounds, monomorphemic words with potential orthographic overlaps, and false compounds. This was done to mirror the prime types used for the real-word targets, and matched in length with the primes of the same condition that are paired with real word targets ($p > 0.102$, all conditions) accordingly. Both sets of 64 real word primes were also matched in length overall ($p > 0.758$). For each condition, half of the nonword targets were constructed to be orthographically similar to the beginning of the prime (e.g., "firepower" and "firt"), while half were constructed to be entirely dissimilar (e.g., "goldfinch" and "dess"). Nonword targets were controlled for length in comparison with the actual (apparent) constituents from each prime (note that both "fire" and "firt" as well as "gold" and "dess" are 4 letters long), though were not always identical ($p > 0.669$, all conditions); in addition, both nonword targets and the potential (apparent) constituents they replaced were matched in length with the real word targets of the same condition ($p > 0.578$, all conditions). All three sets of 64 real word targets, nonword targets and potential (apparent) constituents were matched in length overall as well ($p > 0.900$); in addition, the proportions of both nonword targets and actual (apparent) constituents relative to their corresponding primes was matched for each condition as well as overall ($p > 0.571$). All nonwords were constructed to be pronounceable in English.

Participants saw 128 prime-target pairs in total. Half of the targets were real words, half of them non-words. Two lists were constructed in a Latin square design, to ensure that half of the primes were related to their corresponding target, and half unrelated, both overall and within each condition; the lists were constructed such that, at minimum, all matched stimuli properties remained so in each list. Participants as a result saw the same 128 targets, but only once each, and with a different set of primes preceding real word targets if they had different lists.

As a post-hoc analysis, bigram frequency measures of primes were examined, using MCWord (www.neuro.mcw.edu/mcword). Two measures were analyzed: average frequency of constrained bigrams and average frequency of unconstrained bigrams. (A constrained bigram is an ordered sequence of two letters in a particular position within a word of a given length; an unconstrained bigram is a pair of letters in either order at any position within a word, regardless of word length.) Both measures were found to be controlled within each condition, on the basis of relatedness and/or list ($p > 0.106$, all conditions).[1]

Across conditions, both measures were found to be matched between the transparent compound and opaque compound conditions ($p > 0.554$, both measures) as well as between the orthographic overlap and false compound conditions ($p > 0.252$, both measures), but not controlled otherwise ($p = 0.057$, unconstrained measure, opaque compound vs. false compound conditions; $p < 0.01$, all other comparisons).

Stimuli in the transparent compound, opaque compound, and orthographic overlap conditions were taken largely from Fiorentino & Fund-Reznicek (2009), though the precise use of individual prime stimuli (as related prime, unrelated prime, or prime preceding a nonword) was changed in several cases.

Procedure

[1] The constrained and unconstrained average bigram frequency measures of primes will be incorporated as factors into a future linear mixed-effects model as a follow-up to the post-hoc analysis of bigram frequency.

Participants completed a lexical decision task administered on a personal computer. Stimuli were presented visually in the center of a CRT screen (100 Hz refresh rate) in Courier New size 16 font, using black text on a white background using Paradigm experimental software (Tagliaferri 2005). Stimuli were presented in a random order, different for each participant. Participants were instructed that during each trial they would see a word presented on the screen, which could be a real word in English or a pronounceable nonword, and that their task was to judge whether or not the word was a real word in English as quickly and accurately as possible. They were instructed to respond by hitting the “Y” button for “Yes” for a real word of English, or the “N” button for “No” for a nonword on a response pad, using fingers on their dominant hand.

Each trial began with a 500 ms mask of hash marks equal in number to the number of letters in the prime for the trial. The mask was immediately followed by the prime in lower case letters for 50 ms, and then the target in upper case letters. The target remained on the screen until the participant made a response (by pressing one of the two buttons) or until 2500 ms passed. After a button press or the 2500 ms, the next trial began after a 500 ms intertrial interval.

Participants were given three self-timed rest periods evenly spaced through the experiment (after every 32 trials). They were familiarized with the task with eight practice trials.

Participants

A total of 35 monolingual English-speaking undergraduate students from the University of Kansas participated in the experiment (2 left-handed; 22 females; age range 18-28, mean 19.94), 33 of which were included in the analysis. One participant was excluded from the statistical analysis due to a software crash, and another was excluded from the statistical analysis due to particularly low accuracy on the lexical decision task. All participants had normal or corrected vision. All provided written and informed consent to participate in the study, and received course credit for their participation.

Results

Participants responded to the target trials with high accuracy overall (see Table 2 for mean accuracy by condition):

Table 2: Mean accuracy by condition

Condition	**Accuracy rate**		**Mean difference**
	Related	*Unrelated*	
Transparent	98%	98%	0
Opaque	97%	95%	2%
Orthographic	90%	92%	-2%
False compound	86%	88%	-2%

Accuracy data were analyzed using a generalized linear model. A maximally fit model was generated, with fixed effects of Condition, Relatedness, and Prime and Target Length, Frequency and Orthographic Neighborhood. Factors were removed one by one to reduce the model. Smaller models were compared to larger models at each step by means of a likelihood ratio test; if there was no significant benefit to the larger model, the smaller model was taken as a better fit model. The following accuracy results are from the best fit model, which incorporated fixed effects of Condition, Relatedness, Prime and Target Length, Prime Frequency and Prime Orthographic Neighborhood:

An effect of Condition was found, with the baseline Transparent unrelated condition marginally different from the Opaque condition (z (2092) = -1.937, $p < 0.1$), and significantly different from the Orthographic (z (2092) = -2.270, $p < .05$) and False compound conditions (z (2092) = -2.170, $p < .05$), indicating a reduction in accuracy in all three conditions relative to the baseline. No effect of Relatedness was found (z (2092) = -0.522, $p > 0.1$). Effects of Target Frequency (z (2092) = 7.916, $p < .001$), Target Length (z (2092) = 5.257, $p < 0.001$) and Target Orthographic Neighborhood (z (2092) = 4.863, $p < .001$) were found, indicating an increase in accuracy for targets with higher frequency, length and orthographic neighborhood. An effect of Prime Frequency (z (2092) = -2.858, $p < .01$) was found, indicating reduced accuracy when primes had a higher frequency. No interaction between Condition x Relatedness was found between the baseline Transparent condition and any of the other three conditions.

Response time data were analyzed for real word trials only. Trials with incorrect responses were excluded. On a by-participant basis, response times more than 2.5 standard deviations higher or lower than an individual's average response time were excluded from the analysis. The overall grand average of results, by condition and relatedness, are shown in Table 3 below.

Table 3: Response time (in ms) by condition

Condition	**Response time in milliseconds**		**Mean difference**
	Related	*Unrelated*	
Transparent	599	627	-28
Opaque	614	660	-46
Orthographic	650	644	6
False compound	631	658	-27

Log-transformed reaction times were analyzed using a linear mixed-effects model. As with the accuracy data, a maximally fit model was generated and a best fit model found using the same process. Two analyses were conducted: one including all conditions, but excluding the Phonological Change and Vowel Reduction factors (as those two factors were present in only the Orthographic and False compound conditions), and another including only the Orthographic and False compound conditions, but including the Phonological Change or Vowel Reduction factors.

The maximally fit model for all conditions was generated with fixed effects of Condition, Relatedness, and Prime and Target Length, Frequency and Orthographic Neighborhood, and with crossed random effects of Participant and Item. The following reaction time results are from the best fit model, which incorporated fixed effects of Condition, Relatedness, Target Frequency and Prime Orthographic Neighborhood, and crossed random effects of Participant and Item:

An effect of Condition was found, with the baseline Transparent unrelated condition significantly different from the Opaque condition (t (1905) = 2.530, $p < .05$) as well as the False compound condition (t (1905) = 2.451, $p < .05$), indicating faster response times to targets in the baseline condition. No effect of Condition was found between the baseline Transparent unrelated condition and the Orthographic condition (t (1905) = 1.110, $p > 0.1$). An effect of Relatedness was found, indicating an overall reduction in reaction times when primes and targets were related (t (1905) = -2.876, $p < .01$). An effect of Target Frequency was found, also indicating a reduction in reaction times for targets with higher frequency (t (1905) = -9.748, $p < .001$). An effect of Prime Orthographic Neighborhood was found, indicating faster response times when primes had a larger orthographic neighborhood (t (1905) = -2.241, $p < .05$). No interaction between Condition x Relatedness was found between the baseline Transparent condition and the Opaque and False compound conditions, indicating that the effect of relatedness found in the Transparent, Opaque and False compound conditions was statistically equivalent. A significant interaction of Condition x Relatedness was found between the Transparent and Orthographic conditions (t (1905) = 2.168, $p < .05$), indicating that the effect of relatedness in the Orthographic condition was not statistically equivalent.

To interpret this interaction, a follow-up model was generated for the Orthographic condition only, incorporating (in accordance with the best fit model for all conditions) fixed effects of Relatedness, Target Frequency and Prime Orthographic Neighborhood, and crossed random effects of Participant and Item. An effect of Target Frequency was found, indicating a reduction in reaction times for targets with higher frequency (t (464) = -4.934, $p < .001$). No effect of Relatedness was found (t (464) = 0.299, $p > 0.1$), nor an effect of Prime Orthographic Neighborhood (t (464) = -1.120, $p > 0.1$). The lack of an effect of Relatedness in the

Orthographic condition indicates that interaction found in the model for all conditions can be attributed to a lack of priming effects on the reaction times to targets by related primes in the Orthographic condition only.

The models incorporating the Phonological Change and Vowel Reduction factors to examine the Orthographic and False compound conditions were identical to that of the best fit model for all conditions, with the addition of one of Phonological Change or Vowel Reduction as a fixed effect. Each of these models was compared by means of a likelihood ratio test to a smaller model which did not incorporate Phonological Change or Vowel Reduction as an additional factor. In both instances there was not a significant difference in fit between the models, indicating that the addition of Phonological Change or Vowel Reduction as a fixed effect did not improve the overall fit of the model. This suggests that the two factors did not have a significant impact on the processing of the words containing such factors.

Discussion

In this study, we examined the masked priming effects of semantically transparent and opaque compounds, monomorphemic words that have the appearance of beginning with another monomorphemic word due to an orthographic overlap, and false compounds. We found statistically equivalent priming effects in the transparent, opaque, and false compound conditions only; we found no priming effects in the orthographic condition.

The results of this study are consistent with that of the previous research upon which it is based. These results replicate those of Experiment 1 in Fiorentino & Fund-Reznicek (2009).

Like Fiorentino & Fund-Reznicek (2009), these results have found that masked priming effects in complex words occur regardless of the semantic transparency of those words, even in the absence of an affix, by demonstrating masked priming effects in compound words. Crucially, the results of this study extend this finding to apply to necessarily semantically opaque monomorphemic words that have the appearance of being compound words on an orthographic basis. This demonstrates that a potential exhaustive morphological parse on an orthographic basis is sufficient to drive segmentation in the visual paradigm, even in the absence of apparent affixation.

The results of this study also extend the results of Rastle et al. (2004), who found equivalent masked priming effects in suffixed words alongside semantically opaque words that had the appearance of suffixation due to etymology or orthography. The results of this study extend this finding to apply to the appearance of morphology in the form of multiple root morphemes. Taken together, the overall priming effects in this study are found to apply to the mere appearance of morphology on an orthographic basis even in the absence of multiple factors that could have modulated whether a morphological analysis of the word would be pursued: semantic transparency, status in the mental lexicon as a multimorphemic word, and affixation. The overall picture of complex word processing supported by the results is one that is necessarily decompositional. Targets that showed priming effects were preceded by words that could be exhaustively segmented into a pair of morphemic units. As this process was found to apply even to the false compound condition, the nature of morphological decomposition supported by these results is one that applies initially in an across-the-board manner, on an orthographic basis, and to the appearance of morphology.

Intriguingly, while the results of this study (along with Fiorentino & Fund-Reznicek 2009 and Rastle et al. 2004) show that form alone is not enough to evoke masked priming effects, the priming effects found in the false compound condition here (and the non-etymological portion of the semantically opaque condition in Rastle et al. 2004) are still driven by the segmentation of such words into smaller morphemes on an orthographic basis. The earliest stages of word processing, it appears, are so actively invested in pursuing segmentation that the mind can be momentarily "tricked" by a coincidence of form, provided that such forms match actual, existing morphemes in the mental lexicon. There is evidence, however, that such parses are momentary, as priming effects that are non-masked show emerging effects of semantic relationships (e.g., Rastle et al. 2000).

Thus, our findings are consistent with a view in which the initial stages of complex word processing are involved in a rapid search for morphological structure. While the results of studies like Rastle et al. (2000) suggest that complex word processing rapidly transitions into a stage where the semantic relationships among morphemes are relevant (see also Fiorentino et al. 2014 with regard to compound words), the results of this study alongside the existing masked priming literature examining the role of morphology in complex word processing emphasize the early, automatic primacy of morphological decomposition. A lack of semantic transparency effects in the earliest stages of morphological decomposition thus supports a sublexical model of complex word processing; more specifically, the results of this study support a sublexical model that initially attempts to apply exhaustively in the visual modality on an orthographic basis. The results of the current study do not require assuming whole word access during the course of morphological processing as is posited by dual-route models of morphological decomposition, as this experiment found no interaction between whole word properties and obligatory decomposition: The evidence from these results indicate that the determining factor for whether or not a word is decomposed in the visual modality is the presence of apparent morphological structure on an orthographic basis, independently of its meaning or quantity of morphemes.

In future research, I plan to extend the current study to examine priming of the head/word-final position in semantically transparent compounds, semantically opaque compounds, false compounds, and prime-target pairs with solely orthographic overlap in word-final position. Given that Fiorentino & Fund-Reznicek (2009) found significant and equivalent priming effects for both semantically transparent and opaque compounds in both of their experiments, it is anticipated that the results of my planned second experiment will mimic the results found so far in the one reported here. Such results would replicate the finding that masked morphological priming effects in compounds hold for both non-head and head positions, and again support a picture of decomposition as a process that applies in an early, automatic and across-the-board manner on a morpho-orthographic basis.

Another way in which the current study could be extended would be to examine the same stimulus conditions in the context of long-lag priming. This would provide further interesting research of the nature of morphological decomposition as evidence exists indicating that the overall morphological character of complex word processing is not limited to merely early priming effects as a result of decomposition: long-lag priming experiments have, like masked priming experiments, found effects of morphology that cannot be exclusively attributed to semantics or form (e.g. Marslen-Wilson & Tyler 1998), yet such effects are not at all early in nature. Investigation of the time course and degree of morphological decomposition in complex word processing are of clear ongoing interest to the field.

Summary

The results of this study replicate and extend those of Fiorentino & Fund-Reznicek (2009) and Rastle et al. (2004). The priming effects found in the false compound condition in this study provide new evidence that suggest that morphological decomposition is an early across-the-board part of complex word processing that applies to the orthographic appearance of morphology, regardless of semantic transparency or lexical status of words, and regardless of whether potential constituent morphemes are stems or affixes. Such segmentation of words into potential constituent morphemes at an initial stage supports a sublexical model of complex word processing.

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