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Dissociating morphological and form priming with novel complex word primes: Evidence from masked priming, overt priming, and event-related potentials

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Abstract

Recent research suggests that visually-presented words are initially morphologically segmented whenever the letter-string can be exhaustively assigned to existing morphological representations, but not when an exhaustive parse is unavailable; e.g., priming is observed for both *hunter*→*HUNT* and *brother*→*BROTH*, but not for *brothel*→*BROTH*. Few studies have investigated whether this pattern extends to novel complex words, and the results to date (all from novel suffixed words) are mixed. In the current study, we examine whether novel compounds (*drugrack*→*RACK*) yield morphological priming which is dissociable from that in novel pseudoembedded words (*slegrack*→*RACK*). Using masked priming, we find significant and comparable priming in reaction times for word-final elements of both novel compounds and novel pseudoembedded words. Using overt priming, however, we find greater priming effects (in both reaction times and N400 amplitudes) for novel compounds compared to novel pseudoembedded words. These results are consistent with models assuming across-the-board activation of putative constituents, while also suggesting that morpheme activation may persevere despite the lack of an exhaustive morpheme-based parse when an exhaustive monomorphemic analysis is also unavailable. These findings highlight the critical role of the lexical status of the pseudoembedded prime in dissociating morphological and orthographic priming.

Keywords: compounding, masked priming, overt priming, EEG, morphology, lexical access

A major point of debate in the literature on word recognition involves the extent to which the processing of complex words (e.g., *rainbow*) makes recourse to morphological representations. Approaches to complex word processing include those positing morpheme-based processing either across the board (e.g., Stockall & Marantz, 2006; Taft, 2004) or under some circumstances (e.g., Pinker, 1999), while other approaches hold that either whole-word representations or subsymbolic representations (e.g., orthographic and semantic representations) serve as the representational primitives in complex word processing (e.g., Butterworth, 1983; Bybee, 1995; Kuperman, 2013). Much recent research has engaged this issue using priming paradigms, examining whether complex words (e.g., *hunter*) prime their root (e.g., *hunt*) and whether this priming is dissociable from semantic or orthographic priming. A number of studies from the masked morphological priming literature suggest that morphemes are activated whenever the surface string is exhaustively parsable into potential constituents (Longtin, Segui, & Halle, 2003; McCormick, Rastle, & Davis, 2008; Rastle, Davis, & New, 2004). This activation is seen in masked priming even when the complex word is not semantically transparent (though see Davis & Rastle, 2010, and Feldman, O'Connor, & Moscoso del Prado Mart ń, 2009, for further discussion), and orthographic overlap by itself is argued to not yield similar facilitation (see Rastle & Davis, 2008, for a review). This morpho-orthographic segmentation leads to initial activation of potential constituents even for prime words that ultimately prove to be monomorphemic (e.g., *corner*→*CORN*). Crucially, this activation is not thought to be due to orthographic priming, as prime words that have a pseudoembedded morpheme but cannot be exhaustively segmented into existing morphemes (e.g., *brothel*→*BROTH; broth* is an existing English morpheme but *–el* is not) do not show similar facilitation.

A major challenge in research on morphological processing using real words is that, for complex words that are already lexicalized, effects of morphological relatedness may indeed be the consequence of decomposition, but may also result from other sources such as pre-existing relations between undecomposed whole words and their constituents (e.g., Bybee, 1995), or the result of first activating a stored whole-word representation that under some circumstances leads to morpheme activation (e.g., Giraudo & Grainger, 2000), neither of which entails across-the-board morphological decomposition. On the other hand, *novel* complex words (e.g., *huntity*) provide an ideal test case given that there are no pre-existing lexical or semantic representations for these words; thus, they provide a valuable wedge into the role of morphemes in lexical representation and processing.

While the hypothesis of across-the-board morpho-orthographic segmentation leads to the prediction that such facilitation should extend to novel complex words (e.g., *huntity→HUNT* or *teadesk→TEA*), relatively little priming research has addressed this issue. A masked priming study by Longtin and Meunier (2005) supported this hypothesis. They observed priming for both existing French words (e.g., *rapidement→RAPIDE*; gloss: *quickly→QUICK*) and novel complex words (*rapidifier→RAPIDE*; gloss: *quickify→QUICK*) relative to unrelated primes, but did not find priming for novel words with endings that do not correspond to any morpheme (*rapiduit→RAPIDE*; although *rapid-* is a possible root in French, -*uit* is not an existing affix). In English, Morris, Porter, Grainger, and Holcomb (2011) showed a somewhat similar dissociation, with priming for both real and novel complex primes (*flexible→FLEX* and *flexity→FLEX*, relative to unrelated primes like *painter→FLEX*), of a larger magnitude than that for novel pseudoembedded primes (*flexire→FLEX*). Unlike Longtin & Meunier (2005), however, this dissociation was only observed in the N400 component of event-related brain potentials (ERPs; scalp-recorded measures of brain activity elicited when the participant perceives the target) rather than in behavioral reaction times; furthermore, this dissociation was only found in an experiment using a variety of unrelated control primes, including attested complex words (*painter*), novel complex words (*amusement*), and novel pseudoembedded words (*symbolean*).

Morris et al. (2011) speculate that one possible source of the difference in findings compared to Longtin and Meunier (2005) may be that the orthographic overlap (novel pseudoembedded) condition in Morris et al. (2011) involves fully embedding the target in the prime (e.g., *flexire*→*FLEX*), while that of Longtin and Meunier (2005) does not (e.g., *rapiduit*→*RAPIDE*). However, as Morris et al. (2011) also note, it is not straightforward to expect that orthographic priming of the *brothel*→*BROTH* type should pattern similarly in novel complex word paradigms. The broader orthographic priming literature shows that while orthographic priming with lexicalized primes and targets (e.g., *blur*→*BLUE*) tends not to be facilitative, orthographic priming with novel primes (e.g., *blae*→*BLUE*) does tend to yield facilitation (e.g., Davis & Lupker, 2006). Thus, it is not clear that one should expect novel complex word priming to robustly dissociate from novel pseudoembedded word priming.

If the lexicality of the orthographic prime turns out to be crucial for determining whether pseudoembedded constituents are robustly activated, it suggests that the processing system may be tuned to suppress morphological form activation when morphological representations do not exhaustively match the input (e.g. *brothel* cannot be segmented below the whole-word level) but a monomorpheme that does exhaustively match the input is activated (the whole-word *brothel* itself). In contrast, morphological form activation perseveres when morphological representations do not exhaustively match the input (as in *slegrack*) and the whole form is not a monomorpheme either. Given the limited evidence on this point, we examine novel complex word priming in the current study.

Current Study

The literature reviewed above, investigating whether the morpho-orthographic segmentation of novel complex words is dissociable from orthographic priming, has yielded mixed results. Longtin & Meunier (2005) observe such a dissociation behaviorally, whereas Morris et al. (2011) do not, although they do observe a dissociation in ERPs. In three experiments, we examine constituent activation using novel compound primes and their rightmost constituent (e.g., *drugrack*→*RACK*) as targets; we compare this priming to that of novel pseudoembedded words with overlap in word-final position (e.g., *slegrack*→*RACK*) and unrelated prime-target pairs (e.g., *sepblosh*→*RACK*). Examining the processing of novel compounds in English allows one to investigate the decomposition of novel complex words in a stimulus type for which there is no affix or other formally-regular change associated with the presence of morphological structure. The previous literature has focused on affixed primes, leaving open to what extent decomposition in novel complex primes is driven by the rapid identification of salient, closed-class suffixes (see Longtin et al., 2003, for discussion).

Previous research has focused on priming of the root (initial) constituent in suffixed words, leaving open to what extent constituent priming from novel complex words dissociates from orthographic priming when the overlap is in word-final rather than word-initial position. We thus test novel English compound nouns, which consist of two open-class morphemes, and focus on the word-final (head) position (see, e.g., Fiorentino & Fund-Reznicek, 2009, for masked priming evidence that lexicalized compounds prime their constituents regardless of position or transparency, and Libben, Gibson, Yoon, & Sandra, 1997, for evidence that both first and second constituents prime fully-visible lexicalized compound targets regardless of transparency; see Jarema, Busson, Nikolova, Tsapkini, & Libben, 1999, for discussion of position effects in lexicalized compound processing cross-linguistically). Word-final position priming has not yet been tested in the novel complex word priming literature to our knowledge.

We report here a masked (subliminal) priming study, an overt (supraliminal) priming study, and a simultaneous overt priming/ERP experiment using novel compound and novel pseudoembedded word stimuli. Using masked priming allows us to examine the pattern of early morpho-orthographic segmentation effects with novel compounds for the first time that we are aware of, and provides the most direct comparison with the behavioral priming findings reported in Longtin and Meunier (2005) and Morris et al. (2011), which all used masked primes. We utilize overt priming in our second behavioral study and in our ERP study. This allows us to test whether the novel complex word priming and orthographic priming conditions may diverge more clearly in this paradigm, as has been shown in previous overt priming studies examining morphological and orthographic priming (see e.g., Lavric, Rastle, & Clapp, 2011, and Rastle, Davis, Marslen-Wilson, & Tyler, 2000). ERPs offer a brain-level measure of priming (particularly the N400 component) which Morris et al. (2011) argue to dissociate novel morphological and orthographic priming. Using this cross-method approach, we are able to test (i) whether novel morphological and orthographic priming dissociate in behavioral measures in masked priming or whether, as suggested by Morris et al. (2011), an alternative measure such as N400 is necessary to detect such a dissociation, (ii) whether overt behavioral priming, not tested in either study, would yield a dissociation if masked priming does not, and (iii) whether the dissociation is evident for novel compounds (a word type not tested in either study, but important for the reasons outlined above).

Experiment 1a: Masked Priming

In Experiment 1, we test the masked priming of the word-final constituent in novel compounds (e.g., *drugrack*→*RACK*), the word-final constituent in a novel pseudoembedded word (e.g., *slegrack*→*RACK*), and an unrelated prime-target pair (e.g., *sepblosh*→*RACK*). This design allows us to test whether there is (i) evidence for morphological priming from novel compound primes, and (ii) whether any priming observed in the novel compound condition dissociates from that found for the novel pseudoembedded word prime. Finding a dissociation would be consistent with Longtin and Meunier (2005) and would straightforwardly support the hypothesis of across-the-board morphological segmentation whenever the surface string is exhaustively parsable into potential constituents (e.g., Rastle & Davis, 2008). Finding that priming for the novel compounds does not dissociate behaviorally from orthographic priming would be consistent with the behavioral findings in Morris et al. (2011). Although the finding that novel compounds prime their rightmost constituent would be consistent with the claim that novel compound words are decomposed, in the face of equivalent orthographic priming, such results would not by themselves be straightforwardly attributable to morphological-level priming.

Method

Participants. Data were collected from 79 native English-speaking University of Kansas students (46 females, age range 18-35, mean 20.4). Four of these were excluded from the statistical analysis because they reported seeing the primes. All participants had normal or corrected-to-normal vision. All participants provided their informed consent and received payment, and all methods for the study were approved by the Human Subjects Committee of Lawrence at the University of Kansas.

Stimuli. The experimental prime-target pairs stimuli included 96 target words (e.g., *rack*), each of which was matched with three types of prime: a novel compound prime (e.g., *drugrack*), a novel pseudembedded word with the target embedded in word-final position (e.g., *slegrack*), and an unrelated prime (e.g., *sepblosh*). The three prime conditions (all of which were novel words) were matched for length and number of syllables, as well as for orthographic neighborhood (the number of words of the same length as a given word, differing from the word string by one letter) and bigram frequency (mean position-constrained frequency per million words) using the MCWord database (Medler & Binder, 2005). The prime-target orthographic overlap (50%) was identical across conditions.

Thirty-two additional prime-target pairs with a lexicalized target and an unrelated, novel prime (e.g., *nipetreb*→*GRID*) were added to reduce the overall proportion of prime-target relatedness in the experiment. One hundred twenty-eight prime-target pairs with nonword targets (e.g., *dorntarn*→*MOT*) were added to yield a 1:1 word to nonword target ratio. The morphological structure of the primes, the proportion of prime-target relatedness, prime length, target length, and proportion of prime-target orthographic overlap were identical for word and nonword targets. The stimuli were divided into three lists in a Latin square design, such that in each list, one-third of the stimuli (32 items) appeared in each condition. A full list of stimuli is included in the Appendix.

Procedure. The stimuli were presented in the center of a CRT screen (100Hz refresh rate) in black Courier New font, using the DMDX stimulus presentation software (Forster &

Forster, 2003). Each trial began with the presentation of a forward mask (a string of # marks of the same length as the following prime) for 500ms, followed by the presentation of the prime in lowercase letters for 50ms, and then the target word in uppercase, which remained on the screen until the participant's judgment or a 2500ms timeout, followed by a 320ms inter-trial interval. Participants were told that they would see a string of letters on the screen, and that they were to respond via button-press as quickly and accurately as possible whether that string of letters was a real word of English or not; the index finger of the dominant hand was assigned to "word" and the middle finger to "nonword". The experiment began with six practice trials, followed by the experimental trials, which were randomized for each participant. Participants were provided with self-timed rest periods at sixty-four-trial intervals.

Data analysis. Only responses to the three critical conditions were analyzed. Responses that were incorrect or more than three standard deviations from the participant's mean response time were removed from analysis. All statistical analyses for the behavioral experiments were conducted using linear mixed models (implemented in the `lme4` package of the R statistical computing environment) with a fixed effect of PrimeCondition and crossed random effects of Participant, Item, and List (Baayen, Davison, & Bates, 2008). Maximal random effects structures were used (Barr, Levy, Scheepers, & Tily, 2013).[1] Log-transformed reaction times were analyzed using a linear mixed model, response accuracy using a binomial generalized linear mixed model. The effect of PrimeCondition was tested via log-likelihood test comparing the full model (with full random effects structure) to a maximally similar model without the fixed effect of PrimeCondition. Model coefficients (for dummy-coded planned pairwise comparisons) were considered significant if the 95% confidence interval of the effect size in ms (based on bootstrapping with 500 simulations using the `bootMer{lme4}` function) did not include 0.

Results

Accuracy. Participants' accuracy on each condition is shown in Table 1. Accuracy did not differ significantly across conditions ($\chi^2(2) = 0.903$, $p = .637$).

Table 1

Reaction times (mean and standard error) and lexical decision error rates in behavioral experiments 1a and 1b.

Experiment	Response Time in ms (error %)		
	Novel Compound	Novel Pseudoembedded	Unrelated
Masked (Exp. 1a)	640, SE 3.5 (2.5%)	642, SE 3.5 (3.0%)	653, SE 3.4 (3.3%)
Overt (Exp. 1b)	627, SE 5.7 (2.2%)	645, SE 6.0 (2.1%)	669, SE 6.0 (3.9%)

Reaction times. Reaction times for each condition are shown in Table 1. After exclusion of outliers and incorrect responses, 6903 observations remained for statistical analysis (208 were removed for being incorrect, 89 for extreme reaction times). A significant effect of PrimeCondition was observed ($\chi^2(2) = 7.12$, $p = .028$). Compared to the Unrelated condition, there was significant facilitation for both Novel Compounds ($b = -0.024$, SE = 0.008, CI = -24.20...-5.83, $t = -3.04$) and Novel Pseudoembedded Words ($b = -0.021$, SE = 0.010, CI = -24.23...-0.88, t = -2.12). Reaction time for trials with Novel Compound primes did not differ significantly from reaction time for Novel Pseudoembedded Word primes (b = 0.003, SE = 0.012, CI = -17.35...12.52, t = 0.24).

Discussion

The significant priming effect for novel compounds converges with the studies reviewed above examining novel suffixed words (e.g., Longtin & Meunier, 2005, Morris et al., 2011; see also Beyersmann, Duñabeitia, Carreiras, Coltheart, & Castles, 2013) in suggesting that novel complex words yield facilitation for their constituents. The results of Experiment 1a show that this extends to novel compounds, which do not have an affix or other formally regular indicator of their potential structure. Note that no hyphens or spaces between morphemes were used in this study to help identify morpheme boundaries in compounds, although such features have been argued to help in identifying morpheme boundaries in some cases (see Hyönä, 2012 for a review). Our findings also show that these effects extend to word-final position. Like Morris et al. (2011), but in contrast to Longtin and Meunier (2005), we observed statistically equivalent priming for the novel pseudoembedded word prime condition. Thus, although these findings are consistent with the hypothesis that novel complex words are decomposed into their potential constituents, it is not possible to dissociate the priming effect observed here for the novel compounds from purely orthographic priming.

Experiment 1b: Overt Priming

Since the results of Experiment 1 suggest that morphological priming with novel compound primes does not dissociate from orthographic priming (consistent with Morris et al., 2011 but counter to Longtin & Meunier, 2005), in Experiment 1b we extend the prime duration from 50ms to 250ms, at which duration the primes become fully visible. Previous studies have shown that in priming paradigms with longer stimulus onset asynchronies, distinctions between stimulus types emerge that are not typically evident in masked priming paradigms; for example, effects of semantic transparency (e.g., Rastle et al., 2000; Longtin et al., 2003); likewise, Spanish stem homograph prime-target pairs yielded facilitation in masked priming, but inhibition with fully visible primes (Allen & Badecker, 1999; Badecker & Allen, 2002). In Experiment 1b, we aim to test whether a dissociation emerges between priming effects from novel compound prime-target pairs and novel pseudoembedded word prime-target pairs.

Method

Data were collected from 30 native English-speaking University of Kansas students (21 females, age range 18-29, mean 20.4). All participants had normal or corrected-to-normal vision. All participants provided their informed consent and received payment, and all methods for the study were approved by the Human Subjects Committee of Lawrence at the University of Kansas.

The stimuli, procedure, and data analysis were the same as those used in Experiment 1a, except that the prime duration in Experiment 1b was 250ms.

Results

Accuracy. Participants' error rate for each condition is shown in Table 1. Accuracy did not differ significantly across conditions ($\chi^2(2) = 0.636$, $p = .728$).

Reaction times. Reaction times for each condition are shown in Table 1. After exclusion of outliers and incorrect responses, 2772 observations remained (78 excluded for incorrect responses, 30 for extreme reaction times). The effect of PrimeCondition was significant ($\chi^2(2) = 9.04$, $p = .011$). Compared to the Unrelated condition, there was significant facilitation for both Novel Compounds ($b = 0.063$, SE = 0.011, CI = -52.08...-26.32, $t = -5.67$) and Novel Pseudoembedded Words ($b = -0.036$, SE = 0.011, CI = -36.46...-9.59, $t = -3.33$). Trials with Novel Compound primes also elicited significantly faster responses than trials with Novel Pseudoembedded Word primes ($b = -0.026$, SE = 0.011, CI = -29.99…2.82, $t = -2.38$).

Discussion

Experiment 1b, with fully visible (overt) primes, revealed a significant priming effect for novel compounds and novel pseudoembedded words, as did Experiment 1a with subliminal primes. Crucially, with overt primes the priming effect for novel compounds was significantly larger than that for the novel pseudoembedded words, providing evidence for a dissociation between novel complex words and pseudoembedded words. This finding is consistent with that of Longtin and Meunier (2005) arguing for a dissociation between morphological and form priming with novel primes, although the dissociation only emerged with fully visible primes in the current study. Recall that, although Morris et al. (2011) also did not find such a dissociation in response times in their masked priming experiments, a dissociation between novel complex word priming and pseudoembedded word priming did emerge in the N400 component. In Experiment 2, we examine priming with novel compound prime-target pairs and novel pseudoembedded word prime-target pairs using ERPs, which provide an implicit measure of lexical activation preceding overt lexical decision.

Experiment 2: Event-Related Potentials

A neural signature of priming is a reduction of the amplitude of the N400, a negative-going component emerging around 300-500ms post-onset of the target. N400 priming effects which dissociate morphological and orthographic form overlap have been reported for lexicalized prime-target pairs both in masked priming (e.g., Lavric, Clapp, & Rastle, 2007) and with fully visible primes (e.g., Dominguez, de Vega, & Barber, 2004; Lavric et al., 2011). There is currently very little evidence regarding whether novel complex primes pattern similarly. Morris et al. (2011) do show a greater reduction in posterior N400 (a greater priming effect) for targets following novel affixed primes than those following novel pseudoembedded words, compared to unrelated primes. Given that the present study showed a similar priming pattern behaviorally with overt primes but not masked primes, we utilize ERP with overt primes in Experiment 2 to examine whether this behavioral dissociation is also reflected in the N400. If it is, we predict a greater N400 reduction for the novel compound prime-target pairs (compared to unrelated prime-target pairs) than for novel pseudoembedded word prime-target pairs. This experiment provides the first electrophysiological evidence for novel compound constituent priming, and for the priming of the word-final constituent of a novel complex word of any kind, to our knowledge.

Method

Participants. Data were collected from 31 right-handed native English-speaking University of Kansas students (17 females, age range 18-26, mean 20.4). One of these was excluded from the statistical analysis because of excessive artifacts in her recording (see Data acquisition and analysis). All participants had normal or corrected-to-normal vision and were right-handed (mean laterality quotient 74.5) according to the Edinburgh Handedness Inventory (Oldfield, 1971). All participants provided their informed consent and received payment, and all methods for the study were approved by the Human Subjects Committee of Lawrence at the University of Kansas.

Stimuli. The stimuli for Experiment 2 are those used in Experiments 1a-b.

Procedure. Stimuli were presented in yellow 24-point Courier New font on a black background at the center of a 41-cm CRT monitor in a dimly-lit room. Stimulus presentation was controlled using the Paradigm software package (Tagliaferri, 2005). The procedure was similar to that of Experiment 1b, with the following exceptions: there was no time-out for the behavioral response, participants were instructed not to blink while the stimuli were on the screen, and the inter-trial interval was 1000ms. The recording itself took 20 to 30 minutes.

Data acquisition and analysis. The EEG was continuously recorded using an elastic electrode cap (Electro-Cap International, Inc.) containing 32 Ag/AgCl scalp electrodes organized in a modified 10-20 layout (midline: FPZ, AFZ, FZ, FCZ, CZ, CPZ, PZ, OZ; lateral: FP1/2, F7/8, F3/4, FT7/8, FC3/4, T3/4, C3/4, TP7/8, CP3/4, T5/6, P3/4, O1/2). Polygraphic electrodes were placed at the left and right outer canthi for monitoring horizontal eye movements, above and below each eye for monitoring blinks, and on the left and right mastoids. The left mastoid served as a reference during data acquisition and AFz served as the ground. Impedances for scalp electrodes and mastoids were kept below 5 kΩ. The recordings were amplified by a Neuroscan Synamps2 amplifier (Compumedics Neuroscan, Inc.) with a bandpass of 0.01 to 200 Hz, and digitized at a sampling rate of 1000 Hz.

The continuous EEG was re-referenced to the average of both mastoids and segmented into epochs from 2 seconds before to 3 seconds after the presentation of the critical word. Based on visual inspection, trials containing excessive muscle artifact or alpha activity within the epoch of -1000 to 900ms were excluded from the analysis. An independent components decomposition (ICA; Makeig, Bell, Jung, & Sejnowski, 1996) was applied to remove ocular artifacts in the remaining trials. After artifact correction, the EEG was visually inspected again to remove trials in which any artifact remained. 12.0% of trials were rejected (11.7% of Novel Compound trials, 11.8% of Novel Pseudoembedded Word trials, and 12.5% of Unrelated trials). Only artifact-free trials which were followed by a correct response were included in the subsequent analyses. Participants with fewer than 20 trials remaining for any condition after these procedures were excluded from the analysis, resulting in the exclusion of one participant. Subsequently, data epochs were baseline-corrected using a 750-ms pre-stimulus baseline and averaged to calculate ERPs.

Mean ERP amplitudes over the 300-500ms time window, where the N400 is usually maximal, were compared using repeated measures analyses of variance involving the factors PrimeCondition (Novel Compound, Novel Pseudoembedded Word, Unrelated) and the topographic factor Region, defined by averaging within the following electrode groups: left anterior (F3, FT7, FC3), midline anterior (FZ, FCZ, CZ), right anterior (F4, FC4, FT8), left posterior (CP3, TP7, P3), midline posterior (CPZ, PZ, OZ), and right posterior (CP4, TP8, P4). The Greenhouse-Geisser correction was applied to *F*-tests with more than one degree of freedom in the numerator.

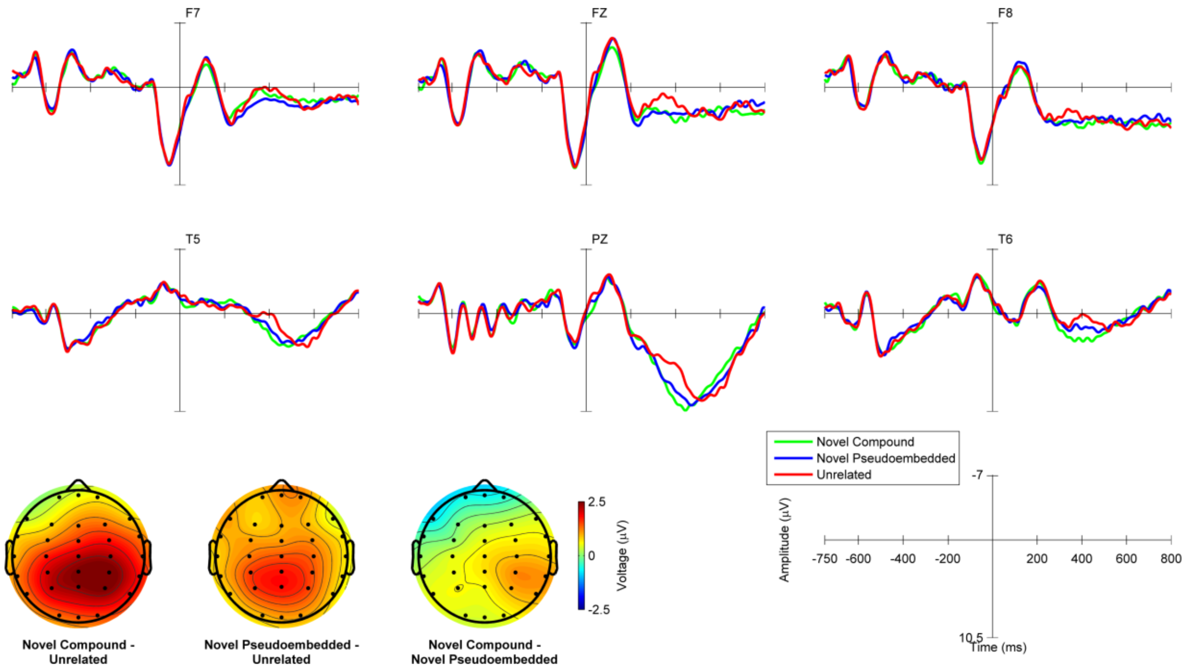

Figure 1. ERP waveforms and topographic maps. Upper portion: Grand average ERPs at six representative electrodes. Lower portion: Topographic maps of the mean differences between each pair of conditions over the 300-500ms time window.

Results

Accuracy. Accuracy was high for all critical conditions (Novel Compounds: 98.02%; Novel Pseudoembedded Words: 96.77%; Unrelated: 96.77%). A generalized linear mixed model revealed no significant differences in accuracy across conditions ($\chi^2(2) = 2.41$, $p = .3$).

ERPs. Grand average ERPs for each condition are shown in Figure 1. Both words preceded by Novel Compound primes and those preceded by Novel Pseudoembedded Word primes showed a reduced centro-parietal negativity, compared to words preceded by Unrelated primes, in the N400 time window. Furthermore, Novel Compound trials showed a less negative ERP than Novel Pseudoembedded Word trials over right posterior sites. Statistical analysis confirmed these observations.

The repeated measures ANOVA on the mean voltages in the 300-500ms time window revealed significant main effects of PrimeCondition ($F(2,58) = 9.2$, MSE = 11.91, $p < .001$) and Region ($F(5,145) = 13.46$, MSE=9.03, $p < .001$), as well as a significant interaction ($F(10,90) = 2.52$, MSE = 0.69, $p = .006$). Resolving the interaction by Region revealed that there were significant simple effects of PrimeCondition in every region of interest except the left anterior (Left anterior: $F(2,58) = 2.07$, $p = .135$; midline anterior: $F(2,58) = 4.46$, $p = .016$; right anterior: $F(2,58) = 5.87$, $p = .005$; left posterior: $F(2,58) = 11.16$, $p < .001$; midline posterior: $F(2,58) = 11.17$, $p < .001$; right posterior: $F(2,58) = 22.72$, $p < .001$). To examine the simple effects of PrimeCondition, we performed *t*-tests between each pair of conditions at each region in which the effect was significant; the results are reported in Table 2. As indicated in the table, both Novel Compound and Novel Pseudoembedded Word primes yielded significantly more positive ERPs than Unrelated primes across the posterior regions. Furthermore, in the right posterior region, a three-way distinction emerged, such that Novel Pseudoembedded Word trials were significantly more positive than Unrelated trials, and Novel Compound trials were significantly more positive than both.

Table 2

Pairwise comparisons for the mean ERP voltages over the 300-500ms time window, in five regions of interest. t *values are from a paired* t*-test with 29 degrees of freedom, and* p *values shown are uncorrected. * indicates values that are significant at the Bonferroni alpha level (.0033), and † indicates values that are marginal at the Bonferroni alpha level (.007).*

MA = Midline Anterior, RA = Right Anterior, LP = Left Posterior, MP = Midline Posterior, RP = Right Posterior.

Comparison	Region				
	MA	RA	LP	MP	RP
Novel compound – Novel pseudoembedded word	t=0.99, p=.328	t=1.31, p=.200	t=1.18, p=.249	t=1.07, p=.293	t=3.48, p=.002*
Novel compound - Unrelated	t=2.71, p=.011	t=3.01, p=.005†	t=4.73, p<.001*	t=5.11, p<.001*	t=6.34 p=.001*
Novel pseudoembedded word - Unrelated	t=1.97, p=.058	t=2.39, p=.024	t=3.29 p=.003*	t=3.33, p=.002*	t=3.50, p=.006*

Discussion

Experiment 2 revealed a significant reduction in N400 both for the novel compound condition and the novel pseudoembedded condition. However, the magnitude of the priming effect was significantly greater for the novel compound condition than for the novel pseudoembedded condition. These results converge with the behavioral priming results from Experiment 1b in showing that both novel compound and novel pseudoembedded conditions yield some facilitation, but that the facilitation is larger for novel compounds. These results also converge with Morris et al. (2011) in demonstrating that morphological and orthographic priming dissociate when probed using N400, an ERP component also associated with priming effects for the constituents of lexicalized complex words (e.g., Dominguez, de Vega, & Barber, 2004; Lavric et al., 2011). Together with Morris et al.

(2011), our findings show that this N400 priming effect extends to novel complex words, and thus cannot only reflect stored associations between and targets that are processed as whole-words and associated through experience, but instead must also reflect morphological decomposition. Our findings show that these effects extend to word-final position, and to novel compounds without predictable closed-class morphology.

General Discussion

The three experiments reported here examined morpheme activation from the word-final constituent in novel compound primes and novel pseudoembedded word primes using masked priming (Experiment 1a), fully visible primes (Experiment 1b), and ERP with fully visible primes (Experiment 2). Across experiments there was evidence of significant facilitation when the prime was a novel compound, as well as evidence of significant facilitation when the prime was a novel pseudoembedded word. Furthermore, when primes were fully visible these prime types dissociated: novel compounds yielded significantly greater reaction time facilitation and N400 attenuation than novel pseudoembedded words.

The results indicating facilitation for the putative constituents of novel compounds converge with a wide range of literature suggesting across-the-board activation of putative morphological constituents, and with previous findings demonstrating that such priming is not limited to affixed words but indeed extends to compounds formed solely from open-class morphemes (e.g., Fiorentino & Fund-Reznicek, 2009). Moreover, the findings are convergent with the growing literature suggesting activation of morphemes embedded in novel complex word primes (e.g., Longtin & Meunier, 2005; Morris et al., 2011). However, when primes were masked, priming for novel pseudoembedded words was indistinguishable from that for novel complex words. Thus, our masked priming results align with those of Morris et al. (2011) in showing facilitation for both novel complex and novel pseudoembedded primes and in eliciting a neurophysiological index of this dissociation (N400 reduction), while they run counter to Longtin and Meunier (2005), in which a dissociation similar to that reported for lexicalized complex vs. pseudoembedded words (i.e., facilitation only for the former) was observed. As discussed above, one possible factor that may affect priming for novel pseudoembedded words may be whether the target is fully embedded in the prime; both the stimuli in Morris et al. (2011) and those of the current study involve full embedding, in contrast to Longtin and Meunier (2005).

Although finding activation of putative constituents in novel compounds is broadly consistent with models assuming across-the-board morpheme-based processing, the facilitation observed for novel pseudoembedded words illustrates that it is not always straightforward to dissociate morphological and orthographic priming when examining novel complex words in the same way as has been often done with lexicalized words. While the presence of a lexicalized monomorpheme (like *brothel*) generally precludes robustly facilitating its pseudoembedded element (*broth*), reaction time priming from novel pseudoembedded words (like *slegrack*) survives (in the present study and in Morris et al., 2011). This contrast underscores the critical role of the lexical status of the prime. When there is no exhaustive morpho-orthographic segmentation of an attested form like *brothel* smaller than the whole word but the whole word is an existing word, its pseudoembedded element is not facilitated (which may be operationalized via inhibition or competition between the representations of the whole-word monomorpheme and its pseudoembedded element; see e.g., Morris et al., 2011). In contrast, when there is no exhaustive morpho-orthographic segmentation of an unattested form like *slegrack* even at the whole-word level, then a pseudoembedded element (e.g., *rack*) may remain active (perhaps due to the lack of inhibitory links or competition between the whole word form, which is unattested, and the attested pseudoembedded element). Investigating novel complex and novel pseudoembedded words thus provides a unique window onto how the morpho-orthographic segmentations system arrives at candidate morphological parses. Novel pseudoembedded word primes (like *slegrack*) reveal perseverant activation of morphological forms (e.g., *rack*) that are not part of an exhaustive segmentation.

The current study (and the few previous studies on novel complex primes) shows that novel complex words also activate their constituents, illustrating that lexicalization is not required to yield morpheme activation. These findings run counter to models accounting for the relationship between lexicalized prime-target prime-target pairs such as *hunter*→*HUNT* as a relationship between separate whole-word forms that become associated through experience (e.g., Bybee, 1995). Recall that in the current study, facilitation was observed in novel compound prime-target pairs (e.g., *drugrack*→*RACK*), for which there cannot be a pre-existing association between the prime and target (as the prime is novel). Instead, we propose that the facilitation results from morphologically decomposing the prime into its constituents, with access to the morpheme *rack* while processing the prime yielding facilitation to the identical, target morpheme *RACK*.

Evidence from the current study which dissociates activation in complex vs. pseudoembedded prime conditions comes not from presence/absence, but from magnitude of behavioral priming and N400 reduction in fully visible priming (see Morris et al., 2011, for evidence that the N400 reduction dissociation is also present for novel suffixed words under masked priming conditions). Finding some activation for pseudoembedded constituents in nonwords is consistent with the finding that, for example, these word types result in longer lexical decision response times than nonwords without pseudoembedded constituents (e.g., Taft & Forster, 1976). There is also a range of psycholinguistic and neurolinguistic evidence suggesting that novel complex words undergo activation of putative constituents and combinatorial processing (see, e.g., Fiorentino, Naito-Billen, Bost, & Fund-Reznicek, 2014 for discussion). The different level of activation for the complex word constituent vs. pseudoembedded element in the fully visible priming study may suggest that activation is stronger when morpho-orthographic segmentation is engaged than when activation only proceeds from letter-level overlap (a distinction also argued for in Morris et al., 2011), although it is also possible that the stronger/more perseverant activation for the novel compound condition arises from the engagement of morpho-semantic representations which may be active to a greater extent if a novel compound is undergoing compositional processing as compared to a novel pseudoembedded word with only one meaning-bearing element (the embedded pseudomorpheme). Further research is needed in order to better understand the circumstances under which priming effects for novel complex word constituents and pseudoembedded elements emerge and how they pattern with respect to one another. Indeed, an important next step in this research will be to examine whether the N400 priming effect that we found when using unmasked priming would extend to masked priming (recall our novel compound and novel pseudoembedded word priming effects did not dissociate behaviorally in masked priming). Likewise, future research should manipulate factors such as the semantic relations between the compound constituents and the interpretability of their combination in order to probe the extent to which combinatorial aspects of compound processing may influence the magnitude of priming observed in the paradigms we tested in the current study.

Summary

The findings from the three experiments reported here are broadly consistent with the claim that the processing of complex words, regardless of lexical status, involves activation of constituents. Although activation of constituents was seen across masked and fully visible priming (both behaviorally and neurophysiologically), priming from novel compounds and novel pseudoembedded words dissociated only in fully visible priming. These results together provide converging evidence, consistent with the burgeoning research on novel complex words, for across-the-board activation for novel complex word constituents, extending this research to English compounding (where there is no affix or other formally regular indicator of morphological constituency) and to word-final position (untested in previous studies, which have examined root priming in words with suffixes). The findings also illustrate the critical role lexical status plays in the processing of pseudoembedded words, both complicating the dissociation of morphological and orthographic activation for novel primes and potentially providing a new window onto the dynamics of morphological analysis during visual word recognition.

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Appendix

Stimuli used in Experiments 1-3

Novel Compound Primes	***Novel Pseudoembedded Word Primes***	***Unrelated Primes***	***Targets***
snowache	chawache	pristrem	ACHE
lifeback	sumeback	sompgome	BACK
soapbag	pronbag	greldem	BAG
bathball	foshball	feskprap	BALL
barband	serband	vogtist	BAND
bullbean	trelbean	forpmerk	BEAN
earbell	dirbell	fiskpap	BELL
darebolt	shiebolt	shempabe	BOLT
spotbow	nertbow	jerglem	BOW
tapebox	himebox	flindun	BOX
sunboy	hanboy	nilkad	BOY
heartbrush	goostbrush	flainchenk	BRUSH
sandbulb	kerdbulb	bremnate	BULB
paintburn	slentburn	slerthosh	BURN
raincard	norncard	floskush	CARD
railcare	brolcare	feshmorp	CARE
skincase	choncase	merbtarn	CASE
soundchair	prundchair	greembleem	CHAIR
birthchip	malshchip	hadgemest	CHIP
treadcloth	plardcloth	shustmoush	CLOTH
handcut	ferdcut	fipslen	CUT
courtday	haistday	blengbim	DAY
truckdevil	slapetrosh	trenkdevil	DEVIL
footeast	leeteast	prilbick	EAST
soyfare	veyfare	daltimp	FARE
cornfight	dainfight	blashlask	FIGHT
stairfish	plourfish	ploudtomp	FISH
treeflake	sareflake	chemplenk	FLAKE
headfriend	mordfriend	treepshorm	FRIEND
mudglass	lodglass	gortfabe	GLASS
lampgum	bispgum	prinkow	GUM
heatgun	tritgun	wodsmid	GUN

foghive	yeghive	sabrund	HIVE
oxhold	uxhold	baprel	HOLD
sidehole	hakehole	larfbast	HOLE
keyhorn	poyhorn	blapdum	HORN
ragjam	tigjam	nolbem	JAM
showland	prawland	poultibe	LAND
worklight	pisklight	panchdrep	LIGHT
houseline	laipeline	maffbraim	LINE
tealink	stalink	detwose	LINK
toothlist	plachlist	trepfreme	LIST
worldload	frandload	flimpnisk	LOAD
paylobe	noylobe	nopgesh	LOBE
stopmaid	plipmaid	frennunk	MAID
southman	plichman	hargpilt	MAN
humpmark	slepmark	fingtesh	MARK
northmat	chishmat	nerlanch	MAT
postmate	mirtmate	filbreng	MATE
tablemill	sorkemill	bramabome	MILL
mouthneck	jeashneck	jaiseclim	NECK
restnight	bortnight	fopshreen	NIGHT
tombnote	falbnote	falphort	NOTE
checkpaste	tronkpaste	moograiste	PASTE
hairpath	flerpath	yongfobe	PATH
bottlepiece	grenfepiece	gurffarnard	PIECE
mousepipe	cradepipe	flampsirk	PIPE
armplane	nomplane	plemberb	PLANE
doorplank	blarplank	mibshrene	PLANK
fairypoint	cralypoint	blembemurt	POINT
bankpool	ferkpool	firtmeeg	POOL
drugrack	slegrack	sepblosh	RACK
mailraft	snelraft	poskmerd	RAFT
searoll	charoll	yitfane	ROLL
fortroom	stitroom	slibnawt	ROOM
bubbleshade	grapleshade	flebarganch	SHADE
bookshell	tenkshell	grendmanch	SHELL
beeshine	nieshine	lupfrant	SHINE
gangship	lirgship	fleptrud	SHIP
clubshop	forbshop	frintren	SHOP
fiberslide	tagarslide	plenshorte	SLIDE
cowspoon	dawspoon	blunfard	SPOON
thumbsteak	prilbsteak	frageclest	STEAK
flagstep	torgstep	pridnusk	STEP
whirlstone	sprelstone	marpebarme	STONE
crewstore	spowstore	fleepidge	STORE
flashstorm	thichstorm	plintnench	STORM

homestream	lidestream	lindshlipe	STREAM
beeftack	haiftack	hasemisk	TACK
airtail	gortail	fomclem	TAIL
standtale	troudtale	brindnorg	TALE
fantime	juntime	glospum	TIME
basetop	tuletop	flimhan	TOP
bloodtown	preedtown	prabefupe	TOWN
wheeltrack	gralltrack	brendfreem	TRACK
draintrap	theantrap	slompresh	TRAP
thunderview	slemporview	slenkaslesh	VIEW
woodwalk	chudwalk	drinbist	WALK
nursewatch	fodgewatch	brimesheme	WATCH
loopwave	feepwave	jushbime	WAVE
girlway	follway	beskteb	WAY
jellywell	marpywell	fappimose	WELL
guidewest	frokewest	premtrest	WEST
logword	higword	pabhest	WORD
bombworm	stibworm	tregnasp	WORM
flooryard	skeeryard	deneskine	YARD

Footnote

[1]The same pattern of results reported below was also observed when using mixed-effects models with only random intercepts, and when using by-subjects and by-items analyses of variance (ANOVA).