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An electrophysiological investigation of early effects of masked morphological priming

Joanna Morris,
Hampshire College, Amherst, MA, USA

Jonathan Grainger, and
CNRS and University of Provence, Marseille, France

Phillip J. Holcomb
Tufts University, Medford, MA, USA

Abstract

This experiment examined event-related responses to targets preceded by semantically transparent morphologically related primes (e.g., farmer-farm), semantically opaque primes with an apparent morphological relation (cornercorn), and orthographically, but not morphologically, related primes (scandalscan) using the masked priming technique combined with a semantic categorisation task. In order to provide information about possible early effects of morphology we focused our analysis on the N250 ERP component. Priming effects for transparent and opaque items patterned together in the early phase of the N250 (200-250 ms), whereas the transparent and orthographic items patterned together in the latter phase of this component (250-300 ms). These results provide further evidence in support of the rapid extraction of morphemes from morphologically complex stimuli independently of the semantic relatedness of the whole and its parts.

Keywords

Evoked potentials; Masked priming; Morphology; Visual word processing

INTRODUCTION

A question that has received considerable attention in the field of word recognition is whether morphologically complex words are decomposed into their constituent morphemes during processing. This phenomenon has been investigated using the priming technique in which the prior presentation of a related word - the prime, facilities processing of the word of interest - the target. It turns out that morphologically related words do prime each other. Morphological priming is a robust phenomenon, which is not readily explained as a simple combination of effects of semantic and form priming.

Several models of word recognition have been proposed in an attempt to account for morphological priming effects. In the prelexical decomposition model of Taft and Forster, (e.g., Taft, 1994; Taft & Forster, 1975) morphologically complex words undergo an affix-stripping procedure to extract the stem prior to lexical access. In contrast, in the supralexical model of Giraudo and Grainger (2000, 2001), complex words are represented as whole units

Correspondence should be addressed to Joanna Morris, School of Cognitive Science, Hampshire College, Amherst, MA 01002, USA. E-mail: jmorris@hampshire.edu.

at the level of form, but morphological relatives are linked to common morphological representations at a higher level of linguistic structure, with the patterns of connectivity determined by semantic transparency. Thus in this model, morphological relatedness is determined only after lexical access has occurred (see Diependaele, Grainger, & Sandra, 2008, for a review of different accounts of morphological processing).

The priming paradigm has proved useful in testing these two models. Although the supralexical model would predict no priming effect for morphological primes that are not semantically related, a number of behavioural studies have shown just such priming effects. Rastle, Davis, Marslen-Wilson, and Tyler (2000) found priming for semantically opaque, morphologically complex primes (e.g., apartment-apart) using a masked priming paradigm with a prime exposure duration of 43 ms, but not with a longer 72 ms prime. Longtin, Segui, and Hallé (2003) reported significant priming from both transparent derived primes (e.g., fillette-fille [little girl-girl]) and pseudo-derived primes (e.g., baguette-bague [little stick-ring]) but no orthographic priming (abricot-abri [apricot-shelter]) with a prime duration of 46 ms. Rastle, Davis, and New (2004) replicated the Longtin et al. (2003) finding while using a mixture of pseudomorphological primes (e.g., corner-corn) and semantically unrelated prime-target pairs that are morphologically related on etymological grounds (e.g., witness-wit).

In a further attempt to distentangle some of the effects of semantic relatedness on morphological priming, Diependaele, Sandra, and Grainger (2005) used the incremental priming technique developed by Jacobs, Grainger, and Ferrand (1995) to investigate the time course of morphological priming effects in French. This technique involves the gradual increase of prime intensity or duration, starting from a level that is too low to influence target processing. They found facilitation for transparent derivations with a 40 ms prime exposure. At 67 ms both transparent and opaque derivations showed a robust facilitation, but transparent primes caused a larger effect than opaque primes. These data are at odds with those of Rastle et al. (2004) and Longtin et al. (2003) who found equally large priming effects for transparent and opaque primes using a prime duration of approximately 40 ms.

Although the behavioural data are suggestive, they do not provide unambiguous evidence that opaque and transparent primes are processed in identical ways, as RT data may reflect the summed contribution of many underlying cognitive processes. In recent years, researchers using behavioural data to test hypotheses about the representation and processing of words have begun to supplement these data with those of other methodologies such as scalp recorded event-related potentials (ERPs). Event-related potentials are well suited to the study of language processing because they have good temporal resolution which allows for the tracking of perceptual and cognitive processes in real time without requiring subjects to produce overt responses that may interfere with the cognitive events related to stimulus processing. Moreover, because ERPs are multidimensional in that we look at not just the latency but also the amplitude, morphology and topography of the ERP components that reflect the cognitive processes of interest - in this case the processes involved in word recognition - they allow us to see differences that may not be visible in RT data.

Grainger and Holcomb have recently proposed a tentative mapping of the ERP components observed in masked repetition priming onto component processes in a general architecture for word recognition - the bimodal interactive activation model (BIAM). Event-related potentials combined with masked repetition priming, have identified a cascade of ERP components - including the P150, N250, and N400 - that appear to reflect processing that proceeds from visual features to orthographic representations and finally to meaning (Grainger & Holcomb, in press; Holcomb & Grainger, 2006, 2007).

The P150 is sensitive to the degree of orthographic overlap between the prime and target items with greater positivities for targets that completely overlap their primes in every letter position and intermediate for targets that overlap in most but not all positions (Kiyonaga, Grainger, Midgley, & Holcomb, 2007). It is also larger to mismatches between prime and target letter case, but more so when the features of the lower- and uppercase versions of the letters are physically different compared with when they are physically similar (Petit, Midgley, Holcomb, & Grainger, 2006). More recent research has shown that this early ERP component can take the form of a bipolar effect across frontal and occipital electrodes (N/P150: Chauncey, Holcomb, & Grainger, 2008; Dufau, Grainger, & Holcomb, 2008). The results from all these studies suggest that this component is sensitive to processing at the level of visual features.

Following the N/P150, the N250 is a negative-going wave that starts as early as 110 ms and peaks around 250 ms. The N250 is sensitive to masked repetition priming of words, being more negative to targets that are unrelated to the previous masked prime word than those that are repeats of the prime. The N250 has a more widespread scalp distribution than the P150, being largest over midline and slightly anterior left hemisphere sites. Words and pseudowords give rise to N250 effects but pictures and letters do not, nor do auditory word targets. The N250 is sensitive to the degree of prime-target orthographic overlap, being somewhat larger for targets that overlap their primes by all but one letter compared to targets that completely overlap with their primes (Holcomb & Grainger, 2006). Hence the N250 has been interpreted as being sensitive to processing at the interface between sublexical and whole word representations.

Finally, masked repetition priming produces a reliable attenuation of the N400 component, a negative going component which typically has a central-posterior maximum (Holcomb & Grainger, 2006). In masked repetition priming, N400 amplitude is larger to unrelated than to related word targets, but this effect does not hold for pseudoword targets (Kiyonaga et al., 2007). Holcomb and Grainger interpret this pattern of findings as reflecting the amount of effort involved in forming links between word and concept representations (the form-meaning interface) with larger N400s indicating a more effortful process.

The above interpretation of ERP components would, however, appear to contrast with other ERP research suggesting much earlier access to whole-word representations, as signalled by the presence of word frequency effects as early as 150 ms post-stimulus onset (e.g., Hauk & Pulvermüller, 2004; Sereno & Rayner, 2003) and semantic effects as early as 250 ms post-stimulus onset (Dell'Acqua, Pesciarelli, Jolicoeur, Eimer, & Peressotti, 2007). There are at least two reasons for such apparent discrepancies, one being methodological and the other theoretical. Methodologically speaking, the masked priming procedure might produce an overall slowing down of target word processing following general interference from prime and mask stimuli. Therefore timing estimates obtained from masked priming would generally be longer than timing estimates obtained from single word presentation procedures. At a theoretical level, if one assumes that visual word recognition proceeds via a series of cascaded activation processes, then ERP components revealed by masked priming could reflect the bulk or central tendency of a given set of processes that are temporally diffuse. Other paradigms might be more sensitive to the starting point of such processes. It is therefore the relative timing of ERP components that provides critical unambiguous information within each particular paradigm.

In one of the first ERP studies of masked morphological priming, Morris, Frank, Grainger, and Holcomb (2007) recorded ERPs and reaction times to targets primed by semantically transparent (e.g., hunter-hunt,) opaque (e.g., corner-corn) and orthographically, but not morphologically, related primes (e.g., scandal-scan) using a lexical decision task and the masked priming technique. They found graded effects of relatedness for both the N250 and the N400 suggesting that semantic transparency might be having a graded influence on priming effects, with transparent primes generating the largest effects, orthographic primes the smallest, and opaque primes in between the two. In addition, there was some evidence for a difference in the spatial distribution of the N250 effect, with the effect being more frontal for transparent items and more posterior for opaque items.

Lavric, Clapp, and Rastle (2007) conducted a similar study with a slightly shorter prime duration and no backward mask between prime and target stimuli. They found an attenuation of the N400 that lasted for the full duration of the component (340-500 ms), but in the orthographic condition, the N400 reduction was only observed in the early part of the component, between 380 and 460 ms. Thus the priming effects indexed by N400 developed later and were more transient in the orthographic condition relative to the transparent and opaque conditions. Lavric et al. (2007) interpreted these results as indicating that a purely structural morphemic segmentation procedure (morpho-orthographic segmentation) operates in the early stages of visual word recognition. However, the analysis of earlier time windows (140-260 ms) also revealed significant priming effects whose spatial distribution varied as a function of prime type, a result in line with the spatial distribution of effects on the N250 component in the Morris et al. (2007) study. Therefore, both studies point to a possible influence of semantic transparency in a relatively early time-window.

Our aim in this study was to conduct a detailed investigation of (a) the relative strength and (b) the time course of priming from transparent (farmer-farm) and opaque (corner-corn) morphologically related primes, with a focus on the N250 component. According to prior research summarised above, it is this component that should be sensitive to any prelexical morphological decomposition that operates independently of semantics. If briefly presented morphologically complex primes enable activation of the embedded root in these prime words, then one would expect to observe a relatively early influence of these primes during target word processing. Activation of the embedded root ‘farm’ during processing of the prime word ‘farmer’ should have a rapid influence on the subsequent processing of the target word ‘farm’ given its early activation during prime processing and the hypothesised prelexical nature of this morpho-orthographic representation of the root. Later effects arising during target word processing will more likely reflect semantic and possibly phonological incompatibilities across prime and target.

In order to provide further information about the time course of priming effects, we combined a typical short prime duration (50 ms) with a longer prime duration (100 ms). The 50 ms prime duration provides a replication ofour earlier study (Morris et al., 2007), while the 100 ms prime duration was chosen with the aim of increasing ERP effect sizes. Event-related potentials provide valuable information concerning the time-course of effects arising during target word processing. Manipulating prime duration provides additional information concerning the time-course of information extraction from prime stimuli. Thus the combined use of ERP recordings and a prime duration manipulation was expected to help iron out some of the remaining inconsistencies concerning the relative timing of priming effects obtained with transparent and opaque primes.

Finally, the present study uses a semantic categorisation task as opposed to the lexical decision task employed in the ERP studies of Morris et al. and Lavric et al., and all prior behavioural research in this area. In this particular paradigm, participants silently read target words for meaning and only respond to a small number of target items (words from a pre-defined semantic category) appearing at random during the experiment. The use of a go/no-go procedure means that participants do not respond on critical trials. Furthermore, the use of a semantic categorisation task is expected to increase semantic-level processing of targets, therefore possibly enhancing effects of semantic transparency. This will provide a first test of whether or not prior observations of effects of semantically opaque primes might be at least be partly due to the type of task that participants have to perform.

METHODS

Participants

The participants for this study were 54 adults (24 men and 30 women). The data from six participants, two male and four females were excluded from analysis, one because of failure to complete the study, one for failing to follow instructions, and four for excessive eye movement or heartbeat artifact. All participants were recruited from the Tufts University community and paid for their participation. The participants ranged in age from 18-26 years (mean 20.8 years). All were right-handed native English speakers with normal or corrected-to-normal vision, and none reported any linguistic or neurological impairment.

Stimuli

The stimuli were the same as those used by Morris et al. (2007). These were 324 prime-target pairs chosen from the CELEX English database. One third (108) of these pairs were morphologically related and had a semantically and orthographically transparent relationship (lender-LEND),one third were not morphologically related and had a semantically opaque relationship[1] (corner-CORN) and one third were orthographically but not semantically or morphologically related (scandal-SCAN).

Semantic relatedness norms were obtained for these items by asking 26 members of the Tufts University and Hampshire College communities to rate each pair of related prime and target words with respect to the degree to which they considered them related in meaning with (1) being ‘very related’ and (5) being ‘completely unrelated’. The mean difference in ratings between items was statistically significant, $F(2, 321)=558.9$, $p<.001$. Pairwise comparisons showed that the ratings in the three priming conditions all differed significantly from each other (all *p*s<.001). The mean rating for the transparent items ($M=1.57$, $SE=.064$), was less than that for the opaque items ($M=3.9$, $SE=0.064$), which in turn was less than that for orthographic items ($M=4.4$, $SE=.064$).

The same morphological suffixes appeared in approximately the same proportions in both the transparent and opaque conditions. In the orthographic condition, the characters at the end of the word that did not overlap with the target did not comprise a regularly used English suffix. The stem was the target item for each pair. Across the three conditions, prime-target pairs were matched on log frequency of the target, $F(2, 321)=1.7$, $p>.1$, log frequency of the prime, $F(1, 321)=1.3$, $p>.1$, length of the target, $F(2, 321)=1.9$, $p>.1$, length of the prime, $F(2, 321)=0.5$, $p>.1$, length of the prime suffix (or in the case of the orthographically related words, the characters at the end of the word that did not overlap with the target), $F(2, 321)=.4$, $p>.1$, and neighbourhood size of the target, $F(2, 321)=1.5$, $p>.1$. The items were randomly divided into two lists of 162 items, containing 54 prime-target pairs in each condition. Targets that were preceded by a related word in one list were preceded by an unrelated word in the other. Unrelated pairs were formed by randomly combining related primes and targets, thus words that served as a related prime in list one, served as an unrelated prime in list two. Each

[1]Rastle et al. (2004) defined a semantically opaque relationship as one that obtains when primes and targets share an apparent morphological relationship, but no semantic relationship, and a purely orthographic relationship as one that obtains when targets are embedded within monomorphemic primes that are not fully decomposable into a stem and affix (e.g., scandal-SCAN), i.e., when the stem is removed from the word in which it is embedded, the remaining letters do not form a recognisable affix. Following Rastle et al. (2004), from now on we use the term ‘opaque’ prime to refer to both etymologically related items (e.g., apartment-APART) and pseudomorphemic items (e.g., corner-CORN).

participant saw each target only once, therefore no participant saw any given target preceded by both a related and an unrelated item.

Procedure

Participants were seated in a comfortable chair is a darkened room at a distance of 76 cm from the computer monitor. Each testing session began with a short practice block, followed by the experimental block. Participants were told that they would see a list of words appear on the computer monitor and were instructed to monitor the list of words for words that referred to articles of clothing and press a button on a game controller when such a word appeared. There were 32 such words in the prime position and 32 in the target position. Participants were told to read all other words passively (i.e., critical stimuli did not require an overt response). Visual stimuli were presented on a 19-inch monitor, with a diagonal viewable screen size of 18 inches, and a width of approximately 14.5 inches, set to a refresh rate of 100 Hz (which allows 10-ms resolution of stimulus control) and located 140 cm in front of the participant. Stimuli were displayed at high contrast as white letters (Verdana font) on a black background. Each letter was 40 pixels tall by 20 pixels wide. The screen resolution was 800 × 600 pixels, and the degree of visual angle subtended by stimuli (3 to 13 characters) ranged from 1.1 to 4.8 degrees. Primes were presented in lowercase letters for either 50 or 100 ms, preceded by a 500 ms random consonant forward mask and a 20 ms random consonant backward mask. Each participant was exposed to only one prime duration, thus prime duration was a between-subjects factor. The mask shared no letters in common with the target or with the prime. The target was then presented in uppercase letters for 300 ms followed by a 1200 ms ITI.

Recording procedure

The electroencephalogram (EEG) was recorded from 29 active tin electrodes held in place on the scalp by an elastic cap (Electrode-Cap International). In addition to the 29 scalp sites, additional electrodes were attached to below the left eye (to monitor for vertical eye movement/ blinks), to the right of the right eye (to monitor for horizontal eye movements), over the left mastoid bone (reference) and over the right mastoid bone (recorded actively to monitor for differential mastoid activity). All EEG electrode impedances were maintained below 5 kΩ (impedance for eye electrodes was less than 10 kΩ). The EEG was amplified by an SA Bioamplifier with a bandpass of 0.01 and 40 Hz and the EEG was continuously sampled at a rate of 200 Hz throughout the experiment.

Data analysis

We calculated the mean voltage in each of two time windows (200-300 ms and 350-450 ms), relative to a 100 ms pre-target baseline. These time epochs were chosen because they correspond to the latency ranges that have been found for the N250, and the N400 in prior research using masked priming. In addition, given the focus on the N250 component in the present study, this epoch was split into two equal intervals corresponding to an early (200-250 ms) and a late (250-300 ms) phase. Critical trials to which subjects had responded incorrectly were discarded as were trials characterised by excessive EOG artifact. This resulted in 7.7% of trials being discarded. This percentage did not vary significantly across experimental conditions ($p>.8$).

The strategy for data analysis involved selecting 12 representative sites distributed across the scalp (FP1, FPz, FP2, F3, Fz F4, C3, Cz, C4, P3, Pz, P4). A mixed model ANOVA with four within-subjects factors - RELATEDNESS, PRIMETYPE, ANTERIOR-POSTERIOR and LATERALITY and one between-subjects factor - PRIME DURATION was used to analyse the data. The RELATEDNESS factor contrasted mean ERP amplitudes for the related and unrelated conditions, while the PRIMETYPE factor contrasted mean ERP amplitudes in the orthographic, opaque, and transparent conditions. To analyse the scalp distribution of the ERP effects, we included two factors, one representing anterior/posterior distribution (ANTERIOR-POSTERIOR) included four levels contrasting electrode locations from the back to the front of the head, and a second representing left/right distribution (LATERALITY) included three levels contrasting electrode locations at left, centre, right sides of the head. The between subjects factor PRIME DURATION contrasted the 50 and 100 ms prime durations. The Geisser-Greenhouse correction was applied when evaluating effects with more than one degree of freedom.

RESULTS

Behavioural data

Participants in the 50 ms prime condition correctly identified an average of 27.7 of 32 clothing items in the target position, 3.9 of 32 clothing items in the prime position and had an average of 1.9 false alarms. Participants in the 100 ms prime condition correctly identified an average of 28.2 of 32 clothing items in the target position, 17.9 of 32 in the prime position and had an average of 3.3 false alarms.

Physiological data

Figures 1 and 2 show the ERPs for the related transparent, opaque, and orthographic targets plotted against the corresponding unrelated targets. Figure 3 shows the difference waves (unrelated minus related targets) for the three different prime types. As can be seen in these plots, ERPs to targets produced an initial small negative-going potential (N1) peaking at between 40 and 70 ms post-target onset, which was followed immediately by a much larger positivity (P2) peaking between 140 and 180 ms. Two relatively widely distributed components followed these early components, the N250 and the N400, which were analysed using the 12-electrode scheme described above. Figure 4 shows an earlier, spatially more focal component (N/P150) seen in prior research (e.g., Chauncey, Holcomb, & Grainger, 2008;Dufau, Grainger, & Holcomb, 2008). This component was analysed with a specific set of occipital and frontal electrodes (O1, Oz, O2, FP1, FPz, FP2).

125-175 ms (N/P150)—An analysis of mean voltages between 125 and 175 ms at only frontal and occipital sites, where the N/P150 effects were expected to be maximal, yielded a Relatedness × Anterior-Posterior interaction, $F(1, 46)=5.05$, $p<.05$. This interaction reflects the typical bipolarity of the N/P150 with greater negativity for related items at occipital sites and greater positivity for these same items at frontal sites. There were no other interactions or main effects involving Relatedness in this analysis.

200-250 ms (early N250)—Between about 200 and 300 ms, responses to targets following unrelated primes were more negative than those to targets following related primes. In the early (200-250 ms) phase of the N250, we found a main effect of Relatedness, $F(1, 46)=57.5$, $p<.001$, as well as a Relatedness × Prime type × Anterior-Posterior interaction, $F(6, 276)=3.23$, $p<.05$. This interaction was caused by a significant N250 effect at all sites for transparent and opaque items (all *p*s<.05), but only at frontal sites for orthographic items ($p_{frontal\_pole}<.001$; $p_{frontal}<.05$; all other *p*s>.1). In this time window, there was also a Relatedness × Laterality interaction, $F(2, 92)=7.97$, $p<.01$, due to a slight right lateralisation of the effect.

250-300 ms (late N250)—In the late (250-300 ms) N250 time window, we again found a main effect of Relatedness, $F(1, 46)=4.8$, $p<.05$, as well as a Relatedness × Prime type × Anterior-Posterior interaction, $F(6, 2764)=3.3$, $p<.05$. The interaction was caused this time by a significant effect only for orthographic and transparent items. For transparent items the effect was significant at both frontal and central sites, for orthographic items the effect was significant only at frontal sites ($p_{orth\_frontal\_pole}$<.01; $p_{trans\_frontal\_pole}$<.01; $p_{frontal}$<.01; $p_{trans\_central}$<.05). It was nonsignificant for the opaque items at all sites (all *p*s>.1).

350-450 ms (N400)—Between about 350 and 450 ms, responses to targets following related primes were less negative than those to targets following unrelated primes. There was a significant main effect of Relatedness, $F(1, 46)=4.1$, p=<.05) as well as a significant Relatedness × Anterior-Posterior interaction, $F(3, 138)=12.2$, $p<.001$, due to the posterior distribution of the effect. There was no interaction between Relatedness and Prime type in this time window.

Re-analyses with ambiguous items removed

The norming of our stimuli with respect to the degree of semantic relatedness between primes and targets (see Appendix) revealed that some items in all three categories were ambiguous, in that their rated semantic relatedness did not correspond to the category to which they had been assigned. Items in the opaque and orthographic categories that received a score of less than 3, indicating that participants viewed these items as somewhat semantically related, and items in the transparent category that received a score of greater than 3, indicating that participants viewed these items as semantically unrelated, were removed from the data, which were then reanalysed. Twenty-two items were removed from the set of opaque items, five from the set of orthographic items and three from the set of transparent items.

The analysis of the N250 time window found results similar to those found using the entire data set. In the early N250 time window we found a main effect of Relatedness, $F(1, 46)=50.35$, $p<.001$, as well as a Relatedness × Prime type × Anterior-Posterior interaction, $F(6, 276)=2.76$, $p<.05$. This interaction was caused by a significant N250 effect at all sites for transparent and opaque items (all *p*s<.05), but only at frontal sites for orthographic items ($p_{frontal\_pole}$<.001; $p_{frontal}$<.01; all other *p*s>.05).

In the late N250 time window, we again found a main effect of Relatedness, $F(1, 46)=5.48$, $p<.05$, as well as a Relatedness × Prime type × Anterior-Posterior interaction, $F(6, 276)=4.25$, $p<.01$. This interaction was caused by a significant effect only for orthographic and transparent items. For transparent items the effect was significant at both frontal and central sites, for orthographic items the effect was significant only at frontal sites ($p_{orth\_frontal\_pole}$<.01; $p_{trans\_frontal\_pole}$<.01; $p_{trans\_frontal}$<.01$p_{trans_central}$<.05). It was nonsignificant for the opaque items at all sites (all *p*s>.1).

In the N400 time window, between 300 and 450 ms we found a significant Relatedness × Anterior-Posterior × Prime duration interaction, $F(3, 138)=3.75$, $p=.04$) due to a significant difference between responses to related and unrelated at posterior sites only in the 100 ms prime duration condition ($p_{parietal\_100\ ms}$<.001; $p_{central\_100\ ms}$=0.01; all other *p*s>.1)

Re-analyses with suffixes equated for repetition

One potential problem with our stimuli (and in fact with those of all previous studies that have contrasted suffixed derived words, pseudocomplex words, and orthographic controls), is that the opaque and transparent primes always included many more repetitions of the final orthographic-morphological strings than the orthographic primes, in which there were almost no repetitions of the final orthographic sequences. In the English language, there is a limited number of derivational suffixes (and pseudosuffixes). Thus, presumed morphological decomposition might have been induced by the many occurrences of the same final orthographic sequences in the transparent and opaque morphological conditions during the course of the experiment.

An analysis of our materials showed that of all the suffixes and non-suffix endings used in our stimulus set, only one ending occurred more than six times, and that was the suffix '-er' which was used 40 times in the opaque condition and 41 times in the transparent condition. Excluding the '-er' items there were no differences in the number of occurrences of different endings across conditions, $F(2, 78)=0.8$, $p>.1$. Thus we undertook an analysis of our data in which we excluded the '-er' items to determine if our effects may have been due to differences in the frequency with which different ending types were used in the experiment.

The results of this new analysis were once again broadly similar to those found using the entire data set. In the early N250 time window we found a main effect of Relatedness, $F(1, 46)=68.7$, $p<.001$, a Relatedness × Anterior-Posterior interaction, $F(3, 138)=5.67.4$, $p<.01$, and a Relatedness × Laterality interaction. An examination of the topographic maps suggested that these interactions arose because the effect was frontal in its distribution, and strongest over midline sites.

The Relatedness × Prime type × Anterior-Posterior interaction was only marginally significant in this re-analysis ($p=.059$). However, an examination of the effects at each site for each condition showed a similar pattern to that found in the main analysis - a significant effect for transparent items at all sites (all ps<.01), for opaque items at frontal and central sites (all ps<.05) and for orthographic items only at frontal pole and frontal sites (all ps<.01). For orthographic items the effect at central sites was marginally significant ($p=.05$).

The main effect of Relatedness was not significant in the later 250-300 ms time window, $F(1, 46)=3.86$, $p>.05$, nor did Relatedness interact with the Anterior-Posterior factor, $F(3, 138)=2.49$, $p>.1$. In this time window, however, we found a significant Relatedness × Prime type interaction, $F(2, 92)=4.03$, $p<.05$, as well as a significant Relatedness × Prime type × Anterior-Posterior interaction, $F(6, 276)=3.0$, $p<.05$. These interactions were caused by a significant N250 effect for orthographic and transparent items. For transparent items the effect was significant at both frontal and central sites, for orthographic items the effect was significant only at frontal sites ($p_{orth\_frontal\_pole}<.01$; $p_{trans\_frontal\_pole}<.01$; $p_{trans\_frontal}<.01$; $p_{trans\_central}<.05$). It was nonsignificant for the opaque items at all sites (all ps>.1).

In the N400 time window, between 350 and 450 ms, we again found a significant effect of Relatedness, $F(1, 46)=5.05$, $p<.05$. The interaction between Relatedness and Prime duration was not significant in this analysis, $F(1, 46)=2.82$, $p>.1$. There was again a significant Relatedness × Anterior-Posterior interaction, $F(3, 138)=8.9$, $p<.01$, due to the posterior distribution of the effect. In this analysis we also found a Relatedness × Laterality, $F(2, 92)=6.8$, $p<.01$, and a relatedness × anterior-posterior × laterality interaction, $F(6, 276)=2.8$, $p<.05$. Follow-up analyses indicated that this interaction was due to the bilateral distribution of the effect at posterior sites (all ps<.05), but a slight right lateralisation at central sites ($p_{right}<.01$; $p_{mid}<.01$; $p_{left}>.05$). There was no interaction between Relatedness and Prime type in this time window.

Re-analyses with items that show a phonological stem change removed

One potential problem with our stimuli (and again a problem for all previous studies that have looked at pseudo-affixation in English), is that the opaque and orthographic primes but not the transparent primes often undergo a phonological change between the stem and the pseudoaffixed form (e.g., tower-tow). An analysis of our materials showed that 35 items in the orthographic condition (32.4%), 31 items in the opaque condition (28.7%), and 3 items in the transparent condition (2.8%) had stems (or embedded words in the case or orthographic items) that underwent a phonological change, including stress shifts. Thus we undertook an analysis of our data in which we excluded these items in order to determine if our effects may have been due to differences in the degree of phonological similarity between the prime and target.

The analysis of the N250 time window found results similar to those found using the entire data set. In the early N250 time window we found a main effect of Relatedness, $F(1, 46)=32.147$, $p<.001$, as well as a Relatedness × Prime type × Anterior-Posterior interaction, $F(6, 276)=4.14$, $p<.05$. This interaction was caused by a significant N250 effect at all sites for transparent and opaque items (all ps<.05), but only at frontal sites for orthographic items ($p_{frontal\_pole}<.001$; all other ps>.05).

In the late N250 time window, we again found a main effect of Relatedness, $F(1, 46)=5.17$, $p<.05$, as well as a Relatedness × Prime type × Anterior-Posterior interaction, $F(6, 276)=5.1$, $p<.01$. The interaction was caused by a significant effect only for orthographic and transparent items. For transparent items the effect was significant at both frontal and central sites, for orthographic items the effect was significant only at frontal sites ($p_{orth\_frontal\_pole}<.01$; $p_{trans\_frontal\_pole}=.01$; $p_{trans\_frontal}=.01$; $p_{trans\_central}=.05$). It was nonsignificant for the opaque items at all sites (all ps>.1).

We also found a Relatedness × Laterality interaction effect, $F_{200\text{-}250}(2, 92)=5.13$, $p<.05$ in the early time window, and a Relatedness × Anterior-Posterior × Laterality interaction, $F_{250\text{-}300}(6, 276)=2.77$, $p<.05$, in the later time window. These interactions were due to the negativity for unrelated items being more pronounced at midline anterior sites ($p_{frontal\_left}>.1$; $p_{frontal\_mid}<.05$; $p_{frontal\_right}>.1$).

Between 350 and 450 ms, at posterior electrode sites, responses to targets following unrelated primes were more negative than those to targets following related primes, resulting in a significant Relatedness × Anteriority interaction, $F(3, 138)=16.5$, $p<.001$. The analysis also revealed a significant Relatedness × Anteriority × Laterality interaction, $F(6, 276)=2.9$, $p<.05$, as well as a significant Relatedness × Laterality × Prime duration interaction, $F(2, 92)=6.4$, $p<.01$. The former was due to the fact that the effect was largest at right centro-parietal sites ($p_{P3}<.01$; $p_{Pz}<.001$; $p_{P4}<.001$; $p_{Cz}<.05$; $p_{C4}<.01$; all other ps>.05), and the latter, to the fact that the effect was larger at right hemisphere sites only in the 100 ms condition ($p_{100\ ms\_mid}<.01$; $p_{100\ ms\_right}<.01$; all other ps>.1). Finally, we also found a three-way interaction between Prime type, Relatedness and Anterior-Posterior due to a significant effect for transparent and opaque primes at centro-parietal sites ($p_{opaq\_parietal}<.001$; $p_{opaq\_central}<.01$; $p_{trans\_parietal}<.05$; all other ps>.05), but no effect for orthographic primes at any site (all ps>.1)

Summary of results

Overall, we found a fairly consistent pattern in the data. In the early phase of the N250 the transparent and opaque items grouped together and the orthographic items behaved differently. More precisely, in this early N250 component, there was a widespread effect for transparent and opaque items,but only a frontal effect for orthographic items. In the later phase of the N250, on the other hand, it was the transparent and orthographic items that grouped together and the opaque items that behaved differently. More precisely, there was a fronto-central effect for transparent and orthographic items in the late N250 component but no effect for opaque items. In the N400 component, priming effects were equally robust for transparent, opaque, and orthographic primes. Our multiple supplementary analyses of the data confirmed the overall analysis with the exception that when items with ambiguous semantic transparency status were excluded, the N400 component only showed significant priming at the long (100 ms) prime duration.

DISCUSSION

Given the inconsistencies in the empirical data concerning the relative strength of priming from transparent (farmer-farm) and opaque (cornercorn) morphologically related primes, and the different time-courses of these priming effects, the goals of the current experiment were twofold: (a) to examine these effects in a semantic categorisation task that emphasises reading for meaning and exploits the full potential of ERP methodology by allowing participants to forego making responses on critical trials; and (b) to use a relatively long (100 ms) as well as a short (50 ms) prime duration in order to boost smaller effects and allow us to see priming effects that may emerge only with longer prime exposure durations. Furthermore, the ERP analyses were focused on a relatively early ERP component, the N250, where we expected to find the clearest evidence for morpho-orthographic segmentation processes.

The N250 component and masked morphological priming

The results of prior research combining ERPs and masked priming (Lavric et al., 2007; Morris et al., 2007) had suggested that differences in the effects of transparent and opaque primes might be most evident in a time-window corresponding to the N250 component identified in the masked priming work of Holcomb and Grainger (2006). What is new in the present study is that we found distinct patterns of priming effects in a division of the N250 into early and late subcomponents. In the early phase of the N250 the transparent and opaque items grouped together and the orthographic items behaved differently, whereas in the later phase of the N250 it was the transparent and orthographic items that grouped together and the opaque items that behaved differently.

Our re-analyses of the N250 data globally confirmed the results of the main analysis. There was however, a hint of an influence of suffix repetition on priming effects in the early N250. The critical distinction between morphological primes (transparent and opaque) and orthographic primes in the early N250 was less evident (i.e., a marginally significant interaction) when items containing the most frequently used suffix (-er) were removed. It is therefore possible that early effects of structural morphological decomposition, found in the present study and in prior research, are being partly driven by the repeated occurrence of a relatively small number of suffixes in both the transparent and opaque primes. Orthographic control primes did not contain such highly repeated orthographic sequences at their endings. Future research should further explore how suffix repetition within an experiment, and suffix frequency in general, might affect morphological priming.

The pattern of priming effects found in the early phase of the N250 provides further support for the prelexical decomposition mechanism proposed by Taft and Forster (1975), and its application to masked morphological priming by Rastle et al. (2004). Finding equivalent priming for transparent and opaque conditions (both different from the orthographic condition), whether it be in behavioural or ERP measures, is an indication that the embedded target words (roots) of the transparent and opaque primes have been equally well extracted (segmented, activated) during prime word processing. Letter-level processing effects were controlled for across the three priming conditions (number and position of shared letters), so the priming effects must reflect some form of orthographic chunking mechanism that operates best for transparent and opaque primes. This conclusion is reinforced by the fact that equivalent priming effects for all three conditions was found in the earlier N/P150 component, thought to reflect the mapping of visual features onto letter-level representations (Chauncey et al., 2008). Furthermore, the fact that we have found evidence for morpho-orthographic segmentation in a semantic categorisation task clearly indicates that prior evidence in favour of such a mechanism was not just a byproduct of the lexical decision task.

The finding of a subdivision in the N250 component is consistent with the results of Grainger, Kiyonaga, and Holcomb (2006) showing a distinction between an early posterior N250 and a late anterior N250. The early posterior effect was driven by an orthographic manipulation (transposed-letter primes) and the late anterior effect by a phonological manipulation (pseudohomophone) primes. The results of Grainger et al. (2006) seem to suggest that the N250 may not be a unitary entity but rather may be composed of distinct subcomponents that index separable orthographic and phonological processes in word recognition. These data suggest that the early N250 effect may reflect prelexical orthographic processing, and the late effect prelexical phonological processing. This fits with a dual-route architecture for word recognition as proposed in the bimodal interactive-activation model (e.g., Grainger, Diependaele, Spinelli, Ferrand, & Farioli, 2003; Holcomb & Grainger, 2007; Kiyonaga et al., 2007). In this model, information from a printed word stimulus can proceed directly to semantics via an orthographic route, or indirectly via the sublexical conversion of orthography to phonology. Furthermore, one recent study has found evidence for a dissociation in the processing of vowels and consonants in the N250 (Carreiras, Gillon-Dowens, Vergara, & Perea, in press). In the Carreiras et al. study, an anterior N250 effect was found when manipulating consonants (in a delayed letter paradigm), whereas a posterior effect was found when manipulating vowels.

Extrapolating from the results of Grainger et al. (2006) to those of the present study, it could be argued that the early N250 effect is due to a structural morpho-orthographic segmentation mechanism that operates equally well on transparent and opaque primes (Rastle et al., 2004). However, as noted above, this early structural orthographic effect might be partly driven by the presence of highly recurring orthographic sequences in the form of derivational suffixes in the morphological primes (transparent and opaque). The late N250 effect, on the other hand, might reflect sublexical phonological processing, and therefore be sensitive to the degree of phonological overlap across primes and targets in a priming paradigm. Examination of the items tested in the present study revealed that the opaque condition includes a large number of items (28.7%) where the stem receives a different pronunciation in the prime than in the target (e.g., TOWER-TOW). Since the transparent condition only included 2.8% of such items, it could well be the greater amount of phonological inconsistency across primes and targets in the opaque condition that is driving the difference between the transparent and opaque priming effects in the later phase of the N250 (lack of priming in the opaque condition). This, however, would appear unlikely given that the orthographic condition contained just as many inconsistent items (32.4%) as the opaque primes, and we did find significant priming in the orthographic condition in the late N250 component. Furthermore, removing the phonologically inconsistent items in a supplementary analysis showed that this did not affect the pattern of priming effects.

Alternatively, and as suggested by Morris et al. (2007), the differential effect on opaque primes found in the late phase of the N250 might reflect the earliest top-down influence from semantics. This would single out the opaque primes due to the combination of two factors. First, the opaque primes, like the transparent primes, undergo fast morpho-orthographic segmentation, leading to isolation of the embedded root and activation of the corresponding meaning. In the case of opaque items, the meaning of the embedded root is incompatible with the meaning of the complete prime word, and this incompatibility could be the source of the reduced priming effects found for these items in the late N250 component. This does not arise for the transparent items since the meaning of the root is compatible with the meaning of the whole word. It would not arise for orthographic items since the embedded target word is not segmented with these primes.

N400 and masked morphological priming

One surprising aspect of the present results is that the N400 component was relatively insensitive to masked morphological priming, particularly at the short (50 ms) prime duration. When items with ambiguous semantic transparency status were excluded, the N400 component only showed significant priming at the long (100 ms) prime duration, and these priming effects were equally robust for transparent, opaque, and orthographic primes. This stands in contradiction with our prior work testing the same stimuli in the lexical decision task (Morris et al., 2007), where we found a clear effect of semantic transparency on priming effects on N400 amplitude with a 50 ms prime duration. On the other hand, Lavric et al. (2007), again with the lexical decision task and using a 40 ms prime duration found equivalent priming for transparent and opaque primes in the N400, both being distinguishable from the orthographic condition.

These variations in the pattern of morphological priming effects as a function of prime duration and task would suggest that the N400 component might not be the best part of the ERP signal to use when seeking evidence for morphological processing. It might be that the N400 is sensitive to conscious processing strategies that would change as a function of task and stimulus parameters. In line with this reasoning, Holcomb et al. (2005) have shown that prime visibility correlates with the size of semantic priming effects observed in the N400 time window. The fact that in the present study priming effects in the N400, but not the N250, increased as a function of prime duration indeed suggests that the mechanisms generating priming effects in the N400 may be less automatised than those governing N250 priming effects. That is the N400, but not the N250, may be sensitive to factors that come into play as prime stimuli become more visible (Holcomb et al., 2005; Holcomb & Grainger, 2007).

Furthermore, although strong effects of masked repetition priming have been found in the N400 with the semantic categorisation task, these effects are much smaller when primes and targets only partially overlap (Holcomb & Grainger, 2006), as was the case in the present study. Indeed, in one of the few studies that has measured ERPs to the same stimuli in both the lexical decision and semantic categorisation tasks (with a manipulation of orthographic neighbourhood size - Holcomb, Grainger, & O'Rourke, 2002), an examination of the waveforms shows a larger and more right-lateralised effect in the lexical decision task. Thus, although the N400 is traditionally associated with semantic-level processing, it might be the case that in non-sentence paradigms (including the present priming paradigm) it is more a reflection of integration processes across form and meaning representations (as argued by Holcomb et al., 2002 and Holcomb & Grainger, 2006, but see Debruille, 2007, for an alternative explanation in terms of knowledge inhibition).

Conclusions

The present study provided further evidence for prelexical segmentation of morphologically complex words, in an experiment where participants silently read target words for meaning. This evidence was present in the early phase of the N250 ERP component, between 200 and 250 ms post-target onset, and suggests that the root representations extracted from morphologically complex prime words influence the subsequent processing of simplex root targets. This morpho-orthographic segmentation seen in the early phase of the N250 operates independently of the semantic relatedness of the embedded root and the whole-word form. Semantic transparency was, however, found to have an influence in the later phase of the N250, between 250 and 300 ms post-target onset. In order to provide more information about the time-course of morpho-orthographic segmentation and the influence of semantic transparency, future research should examine priming effects when primes are free roots, and targets are complex or pseudo-complex words derived from these roots (e.g., farm-farmer, corn-corner).

Acknowledgments

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Appendix

Appendix

Stimulus Type	*Word*	*Stem*	*Neighbourhood size*	*Log freq. of stem*	*Log freq. of stem (per million)*	*Log freq. of word*	*Log freq. of word (per million)*	*Transparency Rating*
Orthographic	strumpet	strum	4	0.30	0.00	0.60	0.00	4.68
Orthographic	burrow	burr	9	1.04	0.30	1.30	0.30	3.76
Orthographic	produce	prod	10	1.11	0.30	2.76	1.52	4.42
Orthographic	nickel	nick	12	1.46	0.30	1.58	0.48	4.54
Orthographic	analog	anal	0	1.53	0.48	1.52	0.48	4.65
Orthographic	spinach	spin	7	1.81	0.60	1.88	0.70	4.27
Orthographic	manicure	manic	5	1.91	0.78	0.95	0.00	4.58
Orthographic	wrench	wren	1	2.00	0.78	1.72	0.60	4.69
Orthographic	singular	sing	16	2.01	0.85	1.92	0.70	5.00
Orthographic	strident	stride	5	2.13	0.95	1.67	0.60	4.76
Orthographic	example	exam	1	2.16	0.95	3.64	2.38	2.81
Orthographic	match	mat	32	2.29	1.08	2.92	1.67	4.65
Orthographic	sternum	stern	1	2.33	1.11	0.90	0.00	4.92
Orthographic	mistake	mist	14	2.36	1.15	2.93	1.68	4.85
Orthographic	pillow	pill	16	2.37	1.15	2.39	1.18	4.54
Orthographic	gazelle	gaze	12	2.46	1.23	1.15	0.30	4.92
Orthographic	slumber	slum	10	1.96	0.78	1.61	0.48	4.73
Orthographic	chaplain	chap	8	2.58	1.34	1.93	0.78	4.73
Orthographic	bellow	bell	15	2.71	1.46	1.11	0.30	4.85
Orthographic	bushel	bush	13	2.88	1.63	1.26	0.30	3.88
Orthographic	earth	ear	12	2.88	1.63	3.34	2.09	4.23
Orthographic	hearth	hear	19	2.92	1.68	1.91	0.70	3.62
Orthographic	decadent	decade	2	2.96	1.72	1.51	0.48	4.85
Orthographic	plantain	plant	5	3.10	1.86	0.95	0.00	4.85
Orthographic	callus	call	16	3.20	1.95	0.30	0.00	4.00
Orthographic	window	wind	15	3.28	2.03	3.38	2.12	4.08
Orthographic	caress	care	26	3.31	2.06	1.34	0.30	4.73
Orthographic	wanton	want	14	3.47	2.21	1.38	0.30	4.73
Orthographic	lateral	late	24	3.56	2.31	2.32	1.11	4.85

Stimulus Type	*Word*	*Stem*	*Neighbourhood size*	*Log freq. of stem*	*Log freq. of stem (per million)*	*Log freq. of word*	*Log freq. of word (per million)*	*Transparency Rating*
Orthographic	carbon	carb	23	3.69	2.44	2.03	0.85	2.35
Orthographic	lesson	less	19	3.92	2.66	2.68	1.45	3.64
Orthographic	ethereal	ether	2	0.00	0.00	0.00	0.00	4.85
Orthographic	appendix	append	0	0.30	0.00	2.08	0.90	4.88
Orthographic	international	intern	1	0.78	0.00	3.34	2.09	4.88
Orthographic	inferno	infer	2	1.04	0.30	1.58	0.48	2.77
Orthographic	twitch	twit	3	1.18	0.30	1.72	0.48	3.96
Orthographic	galaxy	gala	5	1.20	0.30	2.06	0.85	4.27
Orthographic	stubborn	stub	4	1.45	0.48	2.13	0.90	4.92
Orthographic	brothel	broth	5	1.52	0.48	1.69	0.60	4.65
Orthographic	studio	stud	5	1.56	0.48	2.60	1.36	3.50
Orthographic	heaven	heave	6	1.57	0.48	2.77	1.53	4.85
Orthographic	arsenal	arse	3	1.69	0.60	2.00	0.85	4.81
Orthographic	dialog	dial	5	1.72	0.48	2.45	1.23	4.85
Orthographic	basilica	basil	5	1.89	0.70	1.08	0.30	4.77
Orthographic	fuselage	fuse	6	1.95	0.78	1.30	0.30	4.62
Orthographic	salmonella	salmon	2	2.04	0.85	1.15	0.30	4.85
Orthographic	surface	surf	4	2.06	0.85	3.24	1.99	4.73
Orthographic	surgeon	surge	3	2.11	0.90	2.17	0.95	3.65
Orthographic	villain	villa	2	2.22	1.00	1.86	0.70	4.85
Orthographic	twinkle	twin	3	2.45	1.23	1.26	0.30	4.85
Orthographic	plush	plus	3	2.92	1.68	1.67	0.60	4.92
Orthographic	phonetic	phone	3	3.06	1.82	1.04	0.30	3.92
Orthographic	parenthesis	parent	1	3.10	1.86	1.11	0.30	2.88
Orthographic	freeze	free	4	3.56	2.31	1.98	0.78	4.77
Orthographic	corporate	corpora	0	0.60	0.00	2.39	1.18	4.73
Orthographic	sparse	spar	10	1.00	0.00	1.78	0.60	3.92
Orthographic	trollop	troll	2	1.18	0.30	0.30	0.00	4.88
Orthographic	scandal	scan	8	1.32	0.48	2.34	1.11	4.76

Stimulus Type	*Word*	*Stem*	*Neighbourhood size*	*Log freq. of stem*	*Log freq. of stem (per million)*	*Log freq. of word*	*Log freq. of word (per million)*	*Transparency Rating*
Orthographic	grammar	gram	11	1.72	0.60	2.45	1.23	4.35
Orthographic	taciturn	tacit	1	1.73	0.60	1.49	0.48	3.96
Orthographic	marinade	marina	2	1.93	0.78	1.28	0.30	4.65
Orthographic	skill	ski	2	1.97	0.78	2.84	1.59	3.77
Orthographic	general	gene	2	2.06	0.85	3.74	2.49	4.92
Orthographic	coupon	coup	6	2.09	0.90	1.04	0.30	3.00
Orthographic	carton	cart	19	2.17	0.95	1.69	0.60	2.54
Orthographic	dragon	drag	8	2.23	1.00	2.13	0.95	4.08
Orthographic	modern	mode	15	2.33	1.11	3.48	2.23	3.73
Orthographic	pumpkin	pump	11	2.36	1.15	1.49	0.48	4.62
Orthographic	grimace	grim	10	2.43	1.20	1.84	0.70	4.85
Orthographic	rational	ratio	3	2.46	1.23	2.70	1.46	4.58
Orthographic	dollop	doll	12	2.50	1.26	1.20	0.30	4.88
Orthographic	regiment	regime	0	2.54	1.30	2.26	1.04	4.81
Orthographic	catch	cat	25	2.87	1.62	2.61	1.38	4.62
Orthographic	coalesce	coal	8	2.88	1.63	0.70	0.00	4.88
Orthographic	cardinal	card	14	2.89	1.64	2.29	1.08	4.50
Orthographic	shallow	shall	7	2.91	1.67	2.45	1.23	4.58
Orthographic	starch	star	10	2.98	1.73	1.96	0.78	4.81
Orthographic	tallow	tall	17	3.06	1.81	1.34	0.30	4.77
Orthographic	tease	tea	15	3.20	1.95	1.53	0.48	3.68
Orthographic	ballot	ball	20	3.22	1.97	2.15	0.95	4.77
Orthographic	wallop	wall	16	3.38	2.12	0.95	0.00	4.73
Orthographic	wallow	wall	5	3.38	2.12	1.08	0.00	4.12
Orthographic	restrict	rest	13	3.57	2.32	1.45	0.48	4.23
Orthographic	pastoral	past	18	3.69	2.44	1.93	0.78	4.72
Orthographic	partner	part	19	3.94	2.68	2.66	1.43	4.88
Orthographic	demonstrate	demon	5	0.00	0.00	1.88	0.70	4.77
Orthographic	stunt	stun	5	0.48	0.00	1.81	0.60	4.81

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Stimulus Type	*Word*	*Stem*	*Neighbourhood size*	*Log freq. of stem*	*Log freq. of stem (per million)*	*Log freq. of word*	*Log freq. of word (per million)*	*Transparency Rating*
Orthographic	shunt	shun	6	0.70	0.00	0.30	0.00	4.48
Orthographic	squawk	squaw	3	1.11	0.30	0.78	0.00	3.44
Orthographic	colonel	colon	1	1.15	0.30	3.21	1.96	4.85
Orthographic	command	comma	1	1.34	0.30	2.92	1.67	4.54
Orthographic	weird	weir	2	1.43	0.30	2.11	0.90	4.73
Orthographic	electron	elect	2	1.52	0.48	2.04	0.85	4.32
Orthographic	shovel	shove	4	1.56	0.48	1.79	0.60	4.65
Orthographic	candidacy	candid	0	1.62	0.48	1.34	0.30	4.08
Orthographic	smuggle	smug	4	1.65	0.48	0.85	0.00	4.84
Orthographic	quartz	quart	2	1.76	0.60	1.23	0.30	4.85
Orthographic	pulpit	pulp	4	1.85	0.70	1.88	0.70	3.19
Orthographic	rabbit	rabbi	0	1.98	0.78	2.28	1.08	4.84
Orthographic	stirrup	stir	1	2.02	0.85	1.30	0.30	4.73
Orthographic	button	butt	5	2.06	0.85	2.45	1.20	4.58
Orthographic	scrape	scrap	4	2.09	0.90	1.56	0.48	4.69
Orthographic	stampede	stamp	4	2.30	1.08	1.41	0.30	4.77
Orthographic	sight	sigh	4	2.32	1.11	3.23	1.98	3.04
Orthographic	plaintiff	plain	4	2.98	1.73	1.49	0.48	4.58
Orthographic	glade	glad	3	3.06	1.81	1.38	0.30	4.38
Orthographic	extract	extra	0	3.16	1.91	2.12	0.90	4.04
Orthographic	forceps	force	3	3.41	2.16	1.00	0.30	4.88
Opaque	skewer	skew	5	0.00	0.00	1.20	0.30	2.96
Opaque	temper	temp	2	0.78	0.00	2.44	1.20	2.38
Opaque	covenant	coven	7	0.85	0.00	2.07	0.90	2.96
Opaque	wager	wag	21	1.08	0.00	1.15	0.30	4.35
Opaque	clamor	clam	7	1.18	0.30	1.81	0.60	2.69
Opaque	tower	tow	22	1.65	0.48	2.91	1.66	3.38
Opaque	master	mast	21	1.67	0.60	2.92	1.68	4.35
Opaque	quarter	quart	2	1.76	0.60	2.97	1.72	4.92

Stimulus Type	*Word*	*Stem*	*Neighbourhood size*	*Log freq. of stem*	*Log freq. of stem (per million)*	*Log freq. of word*	*Log freq. of word (per million)*	*Transparency Rating*
Opaque	sector	sect	5	1.76	0.60	2.99	1.75	4.69
Opaque	finance	fin	21	1.82	0.70	2.66	1.43	4.27
Opaque	dormant	dorm	8	1.86	0.70	1.78	0.60	3.81
Opaque	rampage	ramp	10	1.90	0.70	1.08	0.30	4.23
Opaque	beaker	beak	12	1.94	0.78	1.34	0.30	4.73
Opaque	limber	limb	6	2.14	0.95	1.04	0.00	4.88
Opaque	tuber	tub	13	2.15	0.95	0.70	0.00	4.19
Opaque	witness	wit	15	2.28	1.08	2.49	1.26	2.31
Opaque	banal	ban	27	2.30	1.08	1.74	0.60	2.88
Opaque	charter	chart	5	2.38	1.15	2.16	0.95	3.35
Opaque	glower	glow	5	2.40	1.18	0.48	0.00	4.08
Opaque	tender	tend	12	2.47	1.23	2.55	1.30	4.73
Opaque	pigment	pig	16	2.51	1.28	1.51	0.48	3.85
Opaque	stringent	string	5	2.60	1.36	1.77	0.60	4.54
Opaque	corner	corn	17	2.64	1.40	3.26	2.01	4.88
Opaque	bowler	bowl	10	2.68	1.45	2.05	0.90	4.42
Opaque	rodent	rod	20	2.70	1.46	1.18	0.30	4.40
Opaque	sandal	sand	15	2.98	1.73	1.30	0.30	3.00
Opaque	fallible	fall	13	3.05	1.80	1.49	0.48	4.23
Opaque	massage	mass	22	3.28	2.03	1.81	0.60	3.35
Opaque	former	form	11	3.63	2.37	3.16	1.91	4.58
Opaque	factor	fact	5	3.96	2.71	2.90	1.65	4.38
Opaque	center	cent	15	4.00	2.75	3.50	2.24	3.54
Opaque	scullery	scull	1	0.00	0.00	1.70	0.60	4.42
Opaque	stilted	stilt	4	0.00	0.00	1.28	0.30	4.72
Opaque	splinter	splint	1	1.11	0.30	1.43	0.30	3.62
Opaque	trolley	troll	2	1.18	0.30	1.98	0.78	4.88
Opaque	grueling	gruel	1	1.36	0.30	1.40	0.30	3.42
Opaque	cryptic	crypt	1	1.41	0.30	1.65	0.48	3.92

Stimulus Type	*Word*	*Stem*	*Neighbourhood size*	*Log freq. of stem*	*Log freq. of stem (per million)*	*Log freq. of word*	*Log freq. of word (per million)*	*Transparency Rating*
Opaque	inventory	invent	4	1.58	0.48	1.83	0.70	4.69
Opaque	glossary	gloss	4	1.63	0.48	1.00	0.30	3.96
Opaque	putty	putt	5	1.70	0.60	1.32	0.30	3.16
Opaque	plumage	plum	6	1.72	0.60	1.30	0.30	4.81
Opaque	number	numb	1	1.85	0.70	3.76	2.51	4.77
Opaque	crooked	crook	4	1.95	0.78	1.95	0.78	4.08
Opaque	discern	disc	3	2.15	0.95	1.15	0.30	4.69
Opaque	brisket	brisk	3	2.17	0.95	1.11	0.30	4.92
Opaque	archer	arch	3	2.36	1.15	1.98	0.78	4.73
Opaque	organic	organ	0	2.38	1.15	2.44	1.20	4.65
Opaque	early	earl	6	2.44	1.20	3.76	2.50	2.19
Opaque	infantry	infant	1	2.57	1.34	2.16	0.95	4.77
Opaque	coaster	coast	3	2.94	1.69	1.20	0.30	4.46
Opaque	counter	count	3	3.01	1.76	2.71	1.46	4.85
Opaque	boarder	board	3	3.19	1.94	0.78	0.00	3.62
Opaque	signet	sign	1	3.21	1.96	1.11	0.30	3.58
Opaque	hearty	heart	4	3.41	2.16	1.93	0.78	4.77
Opaque	render	rend	17	0.30	0.00	1.36	0.30	2.69
Opaque	scamper	scamp	4	0.78	0.00	0.85	0.00	4.77
Opaque	welter	welt	14	0.95	0.00	1.41	0.30	4.27
Opaque	several	sever	7	1.00	0.30	3.63	2.38	4.65
Opaque	gallant	gall	17	1.43	0.30	1.86	0.70	4.84
Opaque	wicker	wick	12	1.61	0.48	1.83	0.70	3.23
Opaque	mother	moth	6	1.72	0.60	3.87	2.61	4.81
Opaque	traitor	trait	3	1.75	0.60	2.04	0.85	4.81
Opaque	tractable	tract	4	1.77	0.60	1.11	0.30	4.42
Opaque	supplement	supple	1	1.78	0.60	2.13	0.90	4.04
Opaque	proper	prop	12	1.86	0.70	3.07	1.82	3.38
Opaque	literal	liter	8	1.89	0.70	1.92	0.78	4.72

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Opaque	bunker	bunk	15	1.99	0.78	2.11	0.90	4.50
Opaque	hinder	hind	11	2.08	0.85	1.08	0.30	3.42
Opaque	inner	inn	8	2.23	1.00	2.91	1.67	4.54
Opaque	luster	lust	12	2.24	1.04	1.51	0.48	3.96
Opaque	mister	mist	14	2.36	1.15	1.84	0.70	2.73
Opaque	pillage	pill	16	2.37	1.15	0.95	0.00	3.04
Opaque	ponder	pond	8	2.41	1.18	1.08	0.30	2.69
Opaque	customer	custom	0	2.45	1.23	2.41	1.18	4.27
Opaque	penance	pen	24	2.54	1.30	1.41	0.30	3.23
Opaque	hostage	host	11	2.57	1.34	1.60	0.48	4.46
Opaque	message	mess	15	2.66	1.41	3.08	1.84	4.23
Opaque	flourish	flour	2	2.67	1.43	1.92	0.78	4.50
Opaque	tailor	tail	14	2.74	1.49	1.65	0.48	4.19
Opaque	flower	flow	11	2.81	1.57	2.68	1.45	4.58
Opaque	shower	show	13	3.27	2.03	2.47	1.23	4.38
Opaque	hospitality	hospital	0	3.28	2.03	2.07	0.90	4.42
Opaque	canal	can	24	3.87	2.62	2.33	1.11	2.64
Opaque	lateral	later	12	3.87	2.62	2.32	1.11	3.23
Opaque	bother	both	6	4.04	2.79	2.28	1.04	2.04
Opaque	manage	man	34	4.25	3.00	2.23	1.00	2.77
Opaque	ample	amp	8	0.90	0.00	2.28	1.08	1.85
Opaque	sniper	snip	4	0.90	0.00	1.34	0.30	4.88
Opaque	whisker	whisk	1	1.23	0.30	0.85	0.00	4.62
Opaque	plucky	pluck	2	1.32	0.30	1.15	0.30	4.85
Opaque	department	depart	1	1.46	0.48	3.30	2.05	4.73
Opaque	gluten	glut	4	1.48	0.48	1.20	0.30	3.69
Opaque	amenable	Amen	1	1.64	0.48	1.70	0.60	3.62
Opaque	facetious	facet	4	1.67	0.60	1.18	0.30	4.15
Opaque	buzzard	buzz	1	1.76	0.60	1.32	0.30	2.88

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Opaque	flicker	flick	5	1.77	0.60	1.88	0.70	4.69
Opaque	question	quest	1	2.06	0.85	3.71	2.46	4.20
Opaque	crafty	craft	4	2.12	0.90	1.56	0.48	2.88
Opaque	ration	rat	28	2.20	1.00	1.98	0.78	2.46
Opaque	brandy	brand	4	2.28	1.04	2.47	1.23	3.23
Opaque	treaty	treat	2	2.38	1.15	2.45	1.23	2.58
Opaque	fleeting	fleet	2	2.41	1.18	1.96	0.78	2.88
Opaque	liquidate	liquid	0	2.71	1.46	0.70	0.00	4.92
Opaque	fruitless	fruit	0	2.71	1.48	1.66	0.60	2.50
Opaque	united	unit	1	3.06	1.81	3.53	2.27	3.08
Opaque	irony	iron	3	3.09	1.84	2.36	1.15	4.27
Opaque	secretary	secret	0	3.21	1.96	3.19	1.94	2.81
Opaque	courteous	court	1	3.35	2.10	1.98	0.78	2.69
Transparent	vendor	vend	11	0.00	0.00	0.00	0.00	1.31
Transparent	editor	edit	2	0.85	0.00	2.70	1.46	1.54
Transparent	buoyant	buoy	3	1.00	0.00	1.80	0.60	2.85
Transparent	cynical	cynic	1	1.38	0.30	2.19	1.00	1.15
Transparent	flexible	flex	9	1.53	0.30	2.39	1.18	1.62
Transparent	different	differ	1	1.68	0.60	3.86	2.60	1.54
Transparent	sailor	sail	15	1.69	0.48	2.01	0.85	1.54
Transparent	blender	blend	5	1.86	0.70	1.36	0.30	1.12
Transparent	stalker	stalk	5	1.90	0.70	0.70	0.00	1.62
Transparent	insistent	insist	0	1.96	0.78	1.90	0.70	1.77
Transparent	loafer	loaf	4	1.97	0.78	0.00	0.00	2.31
Transparent	wreckage	wreck	2	2.09	0.90	1.87	0.70	1.23
Transparent	hanger	hang	15	2.22	1.00	1.18	0.30	1.38
Transparent	boldness	bold	15	2.31	1.08	1.51	0.48	1.46
Transparent	locker	lock	16	2.36	1.15	1.96	0.78	1.62
Transparent	bearable	bear	20	2.52	1.30	1.63	0.48	1.23

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Transparent	package	pack	16	2.52	1.30	2.45	1.23	2.00
Transparent	printer	print	3	2.58	1.36	1.83	0.70	1.35
Transparent	marcher	march	5	2.58	1.36	0.48	0.00	1.27
Transparent	painter	paint	8	2.71	1.46	2.52	1.28	1.31
Transparent	buyer	buy	10	2.75	1.51	1.86	0.70	3.46
Transparent	reader	read	15	2.77	1.52	2.76	1.52	1.50
Transparent	magical	magic	1	2.83	1.58	2.37	1.15	1.23
Transparent	shipment	ship	11	2.90	1.65	1.38	0.30	1.58
Transparent	coolant	cool	12	2.91	1.65	0.85	0.00	2.08
Transparent	coverage	cover	13	3.01	1.77	2.29	1.08	1.65
Transparent	holder	hold	14	3.03	1.79	1.97	0.78	1.42
Transparent	leader	lead	15	3.10	1.85	3.09	1.84	1.23
Transparent	starter	start	6	3.20	1.95	1.86	0.70	2.04
Transparent	actor	act	9	3.41	2.16	2.90	1.65	1.19
Transparent	player	play	6	3.44	2.18	2.72	1.48	1.38
Transparent	backer	back	18	4.34	3.09	1.11	0.30	2.85
Transparent	scalding	scald	5	0.48	0.00	1.57	0.60	1.81
Transparent	mourner	mourn	1	1.04	0.30	0.90	0.00	2.16
Transparent	inhibitory	inhibit	1	1.26	0.30	0.78	0.00	1.12
Transparent	reaction	react	1	1.79	0.60	2.98	1.73	1.15
Transparent	adopted	adopt	2	1.95	0.78	2.05	0.85	2.00
Transparent	baronet	baron	6	2.03	0.85	1.04	0.30	2.15
Transparent	bulbous	bulb	2	2.07	0.85	1.48	0.48	3.60
Transparent	angelic	angel	2	2.29	1.08	1.57	0.48	1.23
Transparent	gloomy	gloom	2	2.29	1.08	2.26	1.04	1.31
Transparent	teacher	teach	5	2.36	1.15	3.15	1.90	1.38
Transparent	legendary	legend	0	2.40	1.18	2.08	0.90	3.62
Transparent	acreage	acre	3	2.43	1.20	1.51	0.48	1.12
Transparent	poetry	poet	5	2.49	1.26	2.58	1.34	1.23

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Transparent	acidic	acid	3	2.59	1.34	1.20	0.30	1.31
Transparent	oxygenate	oxygen	0	2.61	1.38	0.00	0.00	2.54
Transparent	golfer	golf	4	2.74	1.49	1.71	0.60	1.96
Transparent	creamy	cream	3	2.75	1.52	1.88	0.70	1.58
Transparent	dreamer	dream	4	2.96	1.71	1.45	0.48	2.00
Transparent	fleshy	flesh	3	2.97	1.72	1.87	0.70	1.65
Transparent	soften	soft	5	3.14	1.90	1.26	0.30	1.50
Transparent	northern	north	2	3.21	1.96	2.98	1.73	1.38
Transparent	viewer	view	3	3.58	2.33	1.63	0.48	1.31
Transparent	poacher	poach	6	0.70	0.00	1.30	0.30	1.38
Transparent	professor	profess	2	0.70	0.00	3.14	1.89	1.62
Transparent	welder	weld	11	1.08	0.00	1.08	0.30	1.54
Transparent	medical	medic	1	1.11	0.30	3.14	1.89	1.35
Transparent	binder	bind	15	1.56	0.48	1.23	0.30	1.31
Transparent	verbal	verb	7	1.63	0.48	2.35	1.11	1.27
Transparent	lender	lend	17	1.75	0.60	0.95	0.00	1.38
Transparent	looter	loot	16	1.83	0.70	0.00	0.00	1.76
Transparent	zealous	zeal	11	1.94	0.78	1.38	0.30	1.15
Transparent	herbal	herb	7	1.94	0.78	1.59	0.48	2.50
Transparent	singer	sing	16	2.01	0.85	2.12	0.90	1.42
Transparent	leakage	leak	12	2.05	0.85	1.32	0.30	1.15
Transparent	knocker	knock	1	2.28	1.04	1.40	0.30	1.73
Transparent	raider	raid	8	2.29	1.04	1.34	0.30	1.31
Transparent	hunter	hunt	11	2.40	1.18	2.31	1.08	1.84
Transparent	validity	valid	1	2.44	1.20	2.09	0.90	2.15
Transparent	pitcher	pitch	9	2.52	1.30	1.40	0.30	2.58
Transparent	climber	climb	1	2.52	1.30	1.91	0.70	1.23
Transparent	allowance	allow	3	2.60	1.36	2.51	1.28	1.12
Transparent	portable	port	14	2.64	1.40	2.09	0.90	1.31

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Transparent	speaker	speak	4	2.76	1.52	2.49	1.26	1.38
Transparent	bandage	band	16	2.76	1.52	1.83	0.70	2.81
Transparent	renter	rent	17	2.84	1.59	0.48	0.00	2.15
Transparent	boxer	box	16	2.85	1.60	2.09	0.90	1.12
Transparent	claimant	claim	1	2.91	1.66	1.23	0.30	1.46
Transparent	breakage	break	6	2.91	1.67	1.18	0.30	1.19
Transparent	walker	walk	9	3.05	1.80	2.33	1.11	1.19
Transparent	payment	pay	27	3.06	1.82	2.64	1.40	1.27
Transparent	talker	talk	11	3.24	1.99	1.56	0.48	1.35
Transparent	finder	find	15	3.37	2.11	1.00	0.30	1.23
Transparent	clearance	clear	2	3.61	2.36	2.03	0.85	1.31
Transparent	childish	child	3	3.88	2.63	2.38	1.15	1.50
Transparent	eruption	erupt	0	0.78	0.00	1.67	0.60	1.35
Transparent	fizzle	fizz	2	1.00	0.00	0.00	0.00	1.19
Transparent	tufted	tuft	2	1.46	0.48	1.11	0.30	1.23
Transparent	nymphet	nymph	1	1.74	0.60	1.77	0.60	1.48
Transparent	filthy	filth	4	2.00	0.85	2.30	1.08	1.15
Transparent	employer	employ	0	2.02	0.85	2.66	1.41	1.00
Transparent	chilly	chill	4	2.26	1.04	1.99	0.78	1.58
Transparent	floater	float	3	2.29	1.08	1.32	0.30	1.23
Transparent	marshy	marsh	2	2.33	1.11	1.38	0.30	1.38
Transparent	critical	critic	0	2.34	1.11	2.90	1.65	1.12
Transparent	toaster	toast	3	2.40	1.18	1.08	0.30	1.23
Transparent	widowed	widow	0	2.41	1.18	1.76	0.60	1.27
Transparent	alarming	alarm	0	2.54	1.32	2.30	1.08	1.19
Transparent	agreement	agree	0	2.56	1.32	3.02	1.77	1.15
Transparent	bomber	bomb	4	2.71	1.48	1.71	0.60	1.40
Transparent	cloudless	cloud	2	2.73	1.49	1.40	0.30	1.42
Transparent	guilty	guilt	4	2.82	1.57	2.96	1.72	1.27

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Transparent	drunkard	drunk	4	2.82	1.58	1.20	0.30	1.65
Transparent	dietary	diet	9	2.98	1.74	2.02	0.85	1.31
Transparent	risky	risk	7	3.02	1.78	2.02	0.85	1.08
Transparent	bloody	blood	4	3.40	2.15	3.06	1.81	1.62
Transparent	greenery	green	5	3.42	2.17	1.63	0.48	1.42

REFERENCES

Carreiras M, Gillon-Dowens M, Vergara M, Perea M. Are vowels and consonants processed differently? ERP evidence with a delayed letter paradigm. Journal of Cognitive Neuroscience. in press

Chauncey K, Holcomb PJ, Grainger J. Effects of stimulus font and size on masked repetition priming: An ERP investigation. Language and Cognitive Processes 2008;23:183–200. [PubMed: 19590754]

Debruille JB. The N400 potential could index a semantic inhibition. Brain Research Reviews 2007;56:472–477. [PubMed: 18001839]

Dell'Acqua R, Pesciarelli F, Jolicoeur P, Eimer M, Peressotti F. The interdependence of spatial attention and lexical access as revealed by early asymmetries in occipito-parietal ERP activity. Psychophysiology 2007;44(3):436–443. [PubMed: 17371492]

Diependaele, K.; Grainger, J.; Sandra, D. Derivational morphology and skilled reading: An empirical overview. In: Spivey, M.; Joanisse, M.; McRae, K., editors. The Cambridge handbook of psycholinguistics. Cambridge University Press; Cambridge, UK: 2008.

Diependaele K, Sandra D, Grainger J. Masked cross-modal morphological priming: Unravelling morpho-orthographic and morpho-semantic influences in early word recognition. Language and Cognitive Processes 2005;20(1):75–114.

Dufau S, Grainger J, Holcomb PJ. An ERP investigation of location invariance in masked repetition priming. Cognitive Affective and Behavioral Neuroscience 2008;8:222–228.

Giraudo H, Grainger J. Effects of prime word frequency and cumulative root frequency in masked morphological priming. Language and Cognitive Processes 2000;15:421–444.

Giraudo H, Grainger J. Priming complex words: Evidence for supralexical representation of morphology. Psychonomic Bulletin and Review 2001;8:127–131. [PubMed: 11340857]

Grainger J, Diependaele K, Spinelli E, Ferrand L, Farioli F. Masked repetition and phonological priming within and across modalities. Journal of Experimental Psychology: Learning, Memory, and Cognition 2003;29:1256–1269.

Grainger J, Kiyonaga K, Holcomb PJ. The time course of orthographic and phonological code activation. Psychological Science 2006;17:1021–1026. [PubMed: 17201781]

Grainger, J.; Holcomb, PJ. Neural constraints on a functional architecture for word recognition. In: Cornelissen, P.; Hansen, P.; Kringelbach, M.; Pugh, K., editors. The neural basis of reading. Oxford University Press; Oxford: in press

Hauk O, Pulvermüller F. Effects of word length and frequency on the human event-related potential. Clinical Neurophysiology 2004;115:1090–1103. [PubMed: 15066535]

Holcomb PJ, Grainger J. On the time course of visual word recognition: An event-related potential investigation using masked repetition priming. Journal of Cognitive Neuroscience 2006;18:1631–1643. [PubMed: 17014368]

Holcomb PJ, Grainger J. Exploring the temporal dynamics of visual word recognition in the masked repetition priming paradigm using event-related potentials. Brain Research 2007;1180:39–58. [PubMed: 17950262]

Holcomb PJ, Grainger J, O'Rourke T. An electrophysiological study of the effects of orthographic neighborhood size on printed word perception. Journal of Cognitive Neuroscience 2002;14:938–950. [PubMed: 12191460]

Holcomb PJ, Reder L, Misra M, Grainger J. The effects of prime visibility on ERP measures of masked priming. Cognitive Brain Research 2005;24:155–172. [PubMed: 15922167]

Jacobs AM, Grainger J, Ferrand L. The incremental priming technique: A method for determining within-condition priming effects. Perception and Psychophysics 1995;57:1101–1110. [PubMed: 8539086]

Kiyonaga K, Grainger J, Midgley K, Holcomb PJ. Masked cross-modal repetition priming: An event-related potential investigation. Language and Cognitive Processes 2007;22:337–376. [PubMed: 18163153]

Lavric A, Clapp A, Rastle K. ERP evidence of morphological analysis from orthography: A masked priming study. Journal of Cognitive Neuroscience 2007;19:866–877. [PubMed: 17488210]

Longtin C, Segui J, Hallé PA. Morphological priming without morphological relationship. Language and Cognitive Processes 2003;18:313–334.

Morris J, Frank T, Grainger J, Holcomb PJ. Semantic transparency and masked morphological priming: An ERP investigation. Psychophysiology 2007;44:506–521. [PubMed: 17498223]

Petit J, Midgley KJ, Holcomb PJ, Grainger J. On the time course of letter perception: A masked priming ERP investigation. Psychonomic Bulletin and Review 2006;13:674–681. [PubMed: 17201369]

Rastle K, Davis MH, Marslen-Wilson WD, Tyler LK. Morphological and semantic effects in visual word recognition: A time-course study. Language and Cognitive Processes 2000;15:507–537.

Rastle K, Davis MH, New B. The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. Psychonomic Bulletin and Review 2004;11:1090–1098. [PubMed: 15875981]

Sereno SC, Rayner K. Measuring word recognition in reading: Eye movements and event-related potentials. Trends in Cognitive Sciences 2003;7:489–493. [PubMed: 14585445]

Taft M. Interactive-activation as a framework for understanding morphological processing. Language and Cognitive Processes 1994;9:271–294.

Taft M, Forster KI. Lexical storage and retrieval of prefixed words. Journal of Verbal Learning & Verbal Behavior 1975;14:638–647.

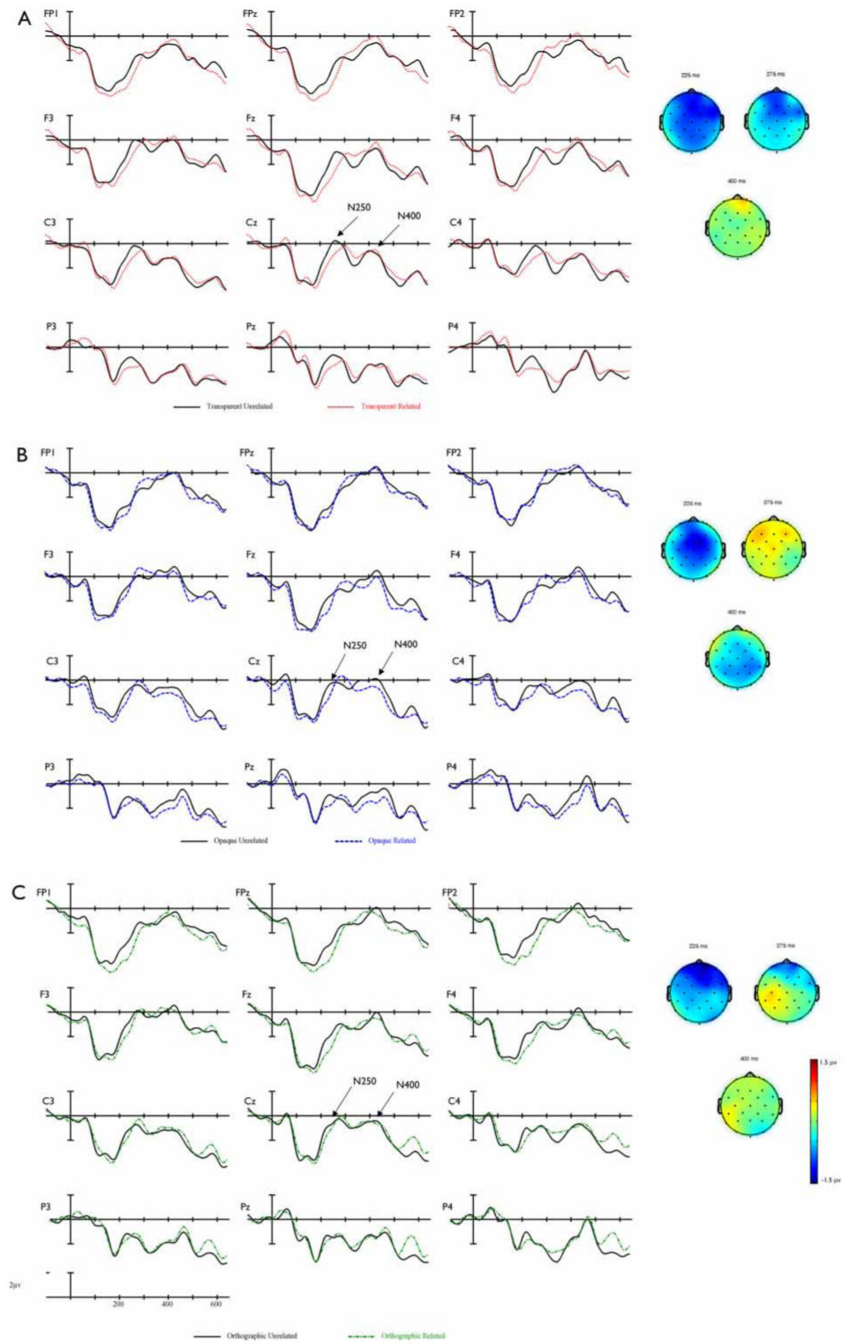

Figure 1.

(opposite). Grand average ERP waveforms elicited by related (solid lines) and unrelated (dotted lines) targets preceded by 50 ms primes in the transparent, opaque, and orthographic conditions at 12 scalp electrode sites. Scalp maps represent voltage differences (unrelated minus related conditions) for each prime type across all electrode sites 355 × 571mm (300 × 300 DPI). To view this figure in colour, please visit the online version of this issue.

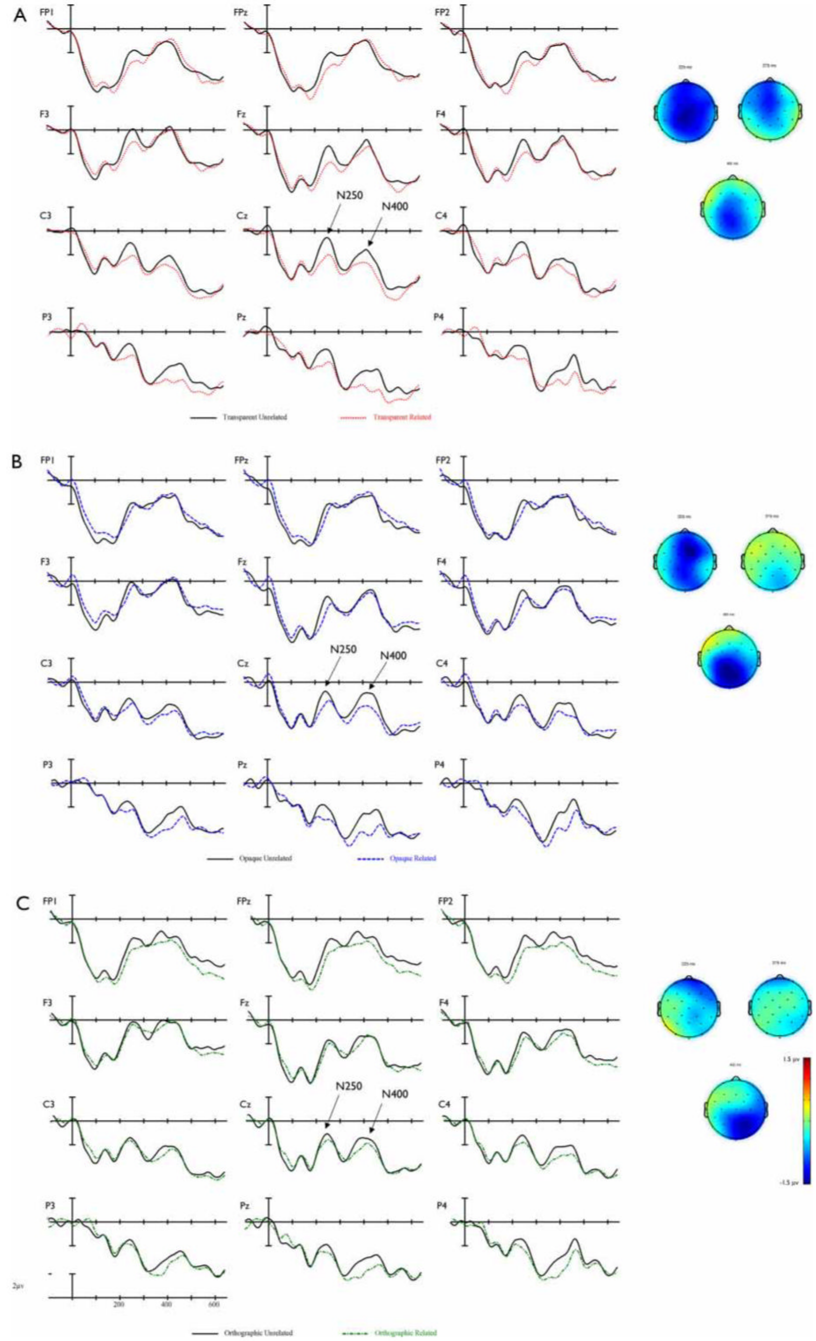

Figure 2.

(opposite). Grand average ERP waveforms elicited by related (solid lines) and unrelated (dotted lines) targets preceded by 100 ms primes in the transparent, opaque, and orthographic conditions at 12 scalp electrode sites. Scalp maps represent voltage differences (unrelated minus related conditions) for each prime type across all electrode sites 355 × 571mm (300 × 300 DPI). To view this figure in colour, please visit the online version of this issue.

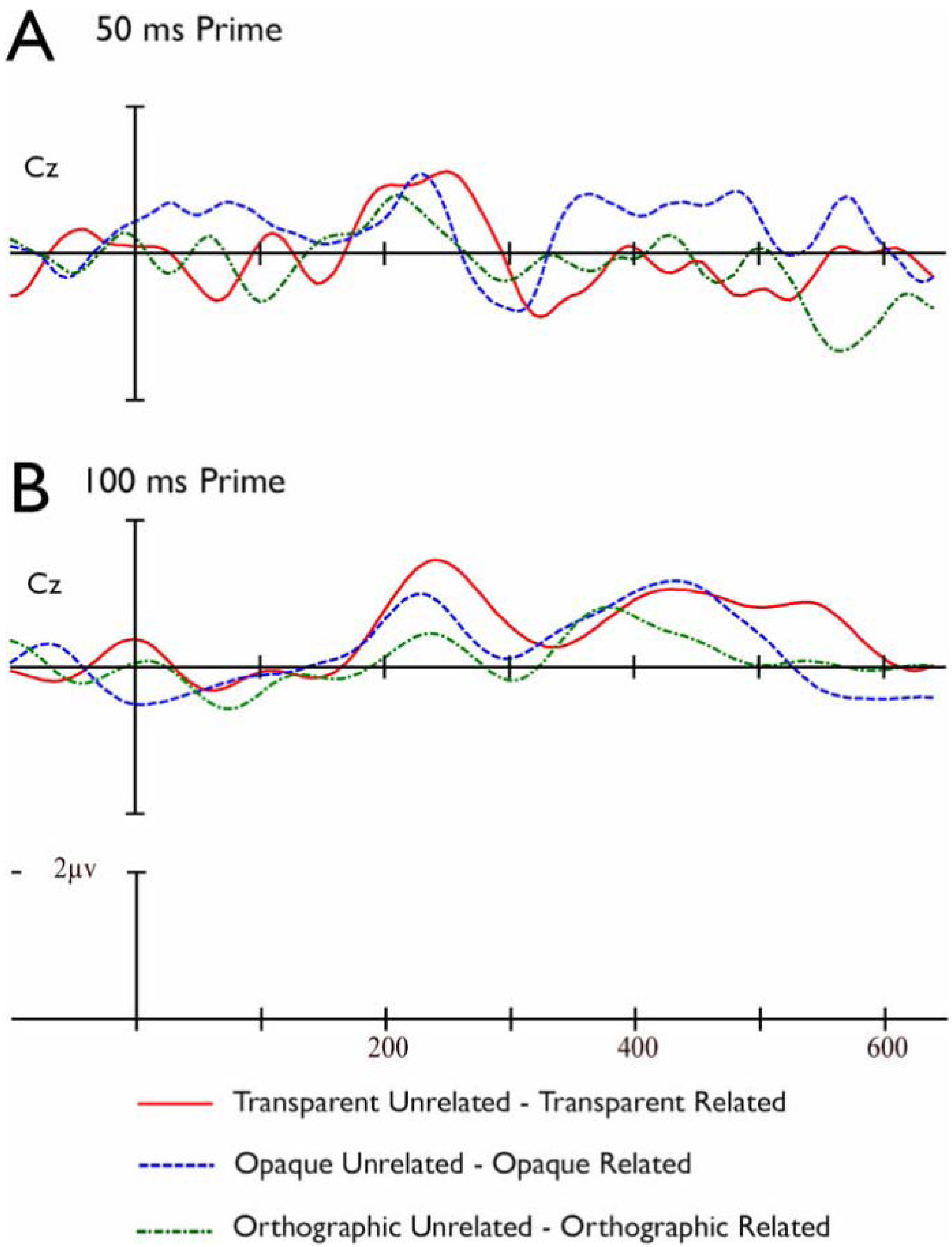

Figure 3.

Grand average difference waves for unrelated minus related targets in the transparent (solid lines), opaque (dotted lines) and orthographic (dashed lines) conditions at electrode site Cz. Panel A shows responses to targets preceded by 50 ms primes, while panel B shows responses to targets preceded by 100 ms primes. 127 × 177mm (300 × 300 DPI). To view this figure in colour, please visit the online version of this issue.

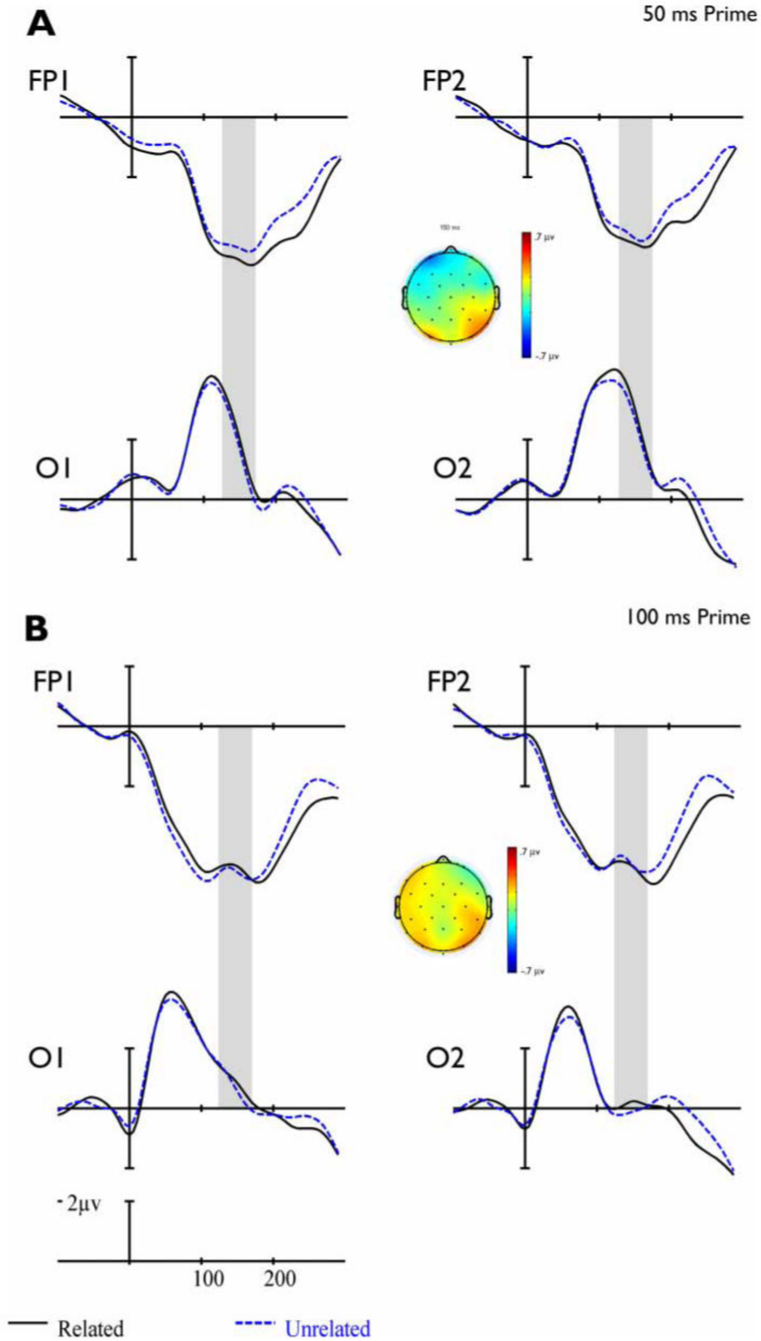

Figure 4.

Grand-averaged ERP waveforms elicited by related (solid lines) and unrelated (dotted lines) targets at electrode sites, FP1, FP2, O1 and O2. The grey shaded area indicates the time window used for analyzing the N/P150 component (125-175 ms). Panel A shows responses to targets preceded by 50 ms primes, while panel B shows responses to targets preceded by 100 ms primes. 279 × 431mm (300 × 300 DPI). To view this figure in colour, please visit the online version of this issue.

TABLE 1

Means and standard deviations for length of prime and target, log frequency of prime and target, and neighbourhood size of target for each condition

Condition	***Orthographic***		***Opaque***		***Transparent***	
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
Suffix Length	2.45	1.01	2.38	0.78	2.35	0.77
Prime Length	6.87	1.34	6.77	1.20	6.94	1.06
Target Length	4.42	0.75	4.39	0.88	4.58	0.74
Orthographic Neighbours (Target)	7.58	6.87	8.06	7.36	6.52	5.81
Log Frequency Target	2.18	0.89	2.16	0.88	2.35	0.77
Log Frequency Prime	1.84	0.78	1.96	0.79	1.80	0.77