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Research Report

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ARTICLE INFO

Article history:
Accepted 6 July 2014

Keywords:
Morphological priming
Semantic processing
Orthographic processing
Lexical Decision
N400
Visual word recognition
Time course
Language

ABSTRACT

Previous research has yielded conflicting results regarding the onset of semantic processing during morphological priming. The present study was designed to further explore the time-course of morphological processing using event-related potentials (ERPs). We conducted a primed lexical decision study comparing a morphological (*LAVAGE – laver* [*washing – wash*]), a semantic (*LINGE – laver* [*laundry – wash*]), an orthographic (*LAVANDE – laver* [*lavender – wash*]), and an unrelated control condition (*HOSPICE – laver* [*nursing home – wash*]), using the *same* targets across the four priming conditions. The behavioral data showed significant effects of morphological and semantic priming, with the magnitude of morphological priming being significantly larger than the magnitude of semantic priming. The ERP data revealed significant morphological but no semantic priming at 100–250 ms. Furthermore, a reduction of the N400 amplitude in the morphological condition compared to the semantic and orthographic condition demonstrates that the morphological priming effect was not entirely due to the semantic or orthographic overlap between the prime and the target. The present data reflect an early process of semantically blind morphological decomposition, and a later process of morpho-semantic decomposition, which we discuss in the context of recent morphological processing theories.

1. Introduction

The vast majority of words we read are morphologically complex, such as *happiness*, which is composed of the morphemes *happy* and *ness*. Although researchers agree that these words are analyzed into their morphemic constituents during visual word recognition, they disagree about the nature of the decomposition process. One hypothesis considers that morphologically complex words are always initially processed through rapid morphemic segmentation based

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solely on orthographic information, followed by the later activation of their semantic properties (Beyersmann et al., 2011; Lavric et al., 2007, 2012; Longtin and Meunier, 2005; Longtin et al., 2003; Rastle et al., 2004). This hypothesis is based on evidence from a substantial number of masked priming studies (see Rastle and Davis, 2008, for a review), showing that words with a morphological structure prime their stems (e.g. *darker* – *DARK*) as much as words with a pseudo-morphological structure (e.g. *corner* – *CORN*). The alternative hypothesis suggests that rapid access to semantic information of morphemes can constrain the initial decomposition of complex words into their morphemic constituents. This hypothesis has been corroborated by studies showing that the magnitude of morphological priming is greater than the magnitude of pseudo-morphological priming (e.g., Diependaele et al., 2011; Feldman et al., 2009).

Only recently, neurophysiological studies have been able to advance this debate by providing more detailed insights into the temporal aspects of morphological processing during visual word recognition. A number of researchers have started to use high-temporal resolution recordings of event-related brain potentials (ERPs) to investigate the influences of orthography and semantics during morphological processing (Barber et al., 2002; Dominguez et al., 2004; Lavric et al., 2011, 2012; Morris et al., 2007, 2008, 2011, 2013). The majority used masked primed lexical decision to look at both response latencies and ERPs in different time windows. The ERP data across different studies showed no difference between morphological priming (e.g., *darker* – *DARK*) and pseudo-morphological priming (e.g., *corner* – *CORN*) in the earlier time windows (for converging evidence from MEG, see Lewis et al., 2011; Solomyak and Marantz, 2009, 2010). However, when visible primes (Lavric et al., 2011) or longer prime presentations were used (e.g. Morris et al., 2007), morphological priming effects continued to be significant, whereas pseudo-morphological priming effects tended to be absent or reduced in the later time windows (see also Lavric et al., 2012 for related evidence from unprimed lexical decision).

For instance, in an early time window (340–460 ms), Lavric et al., (2007) found reduced N400 amplitudes in both the morphological and pseudo-morphological conditions, but not in the orthographic condition (e.g., *brothel* – *BROTH*), which was taken to suggest that morphologically complex words are decomposed in early stages of visual word recognition on the basis of their morpho-orthographic properties. This pattern persisted in a later time window (460–500 ms), showing that there was no indication of semantics influencing morphological decomposition. Interestingly, these findings are complemented by the results from another study by the same group of authors (Lavric et al., 2011), which differed from Lavric et al. (2007) in one crucial aspect in that the primes were not masked. Lavric et al. (2011) presented primes for 200 ms and found that in the early portion of N400, morphological and pseudo-morphological priming effects were similar, just like in masked priming. But from 370 ms onwards, morphological priming was greater than pseudo-morphological priming (see Fig. 1 in Lavric et al., 2011; for converging evidence, see also Morris et al., 2007). This suggests that influences from semantics onto morphological priming are more likely to arise when participants are given enough time to thoroughly process the prime. Lavric et al.'s results support the hypothesis that while initial morphological processing stages are purely based on orthographic analysis, morphological decomposition begins to benefit from semantic information during later processing. This is consistent with theories which propose that the initial morphological processing stages are semantically 'blind' (e.g., Lavric et al., 2007; Longtin and Meunier, 2005; Rastle et al., 2004) and thus challenges theories according to which semantic processing already begins to influence morphological

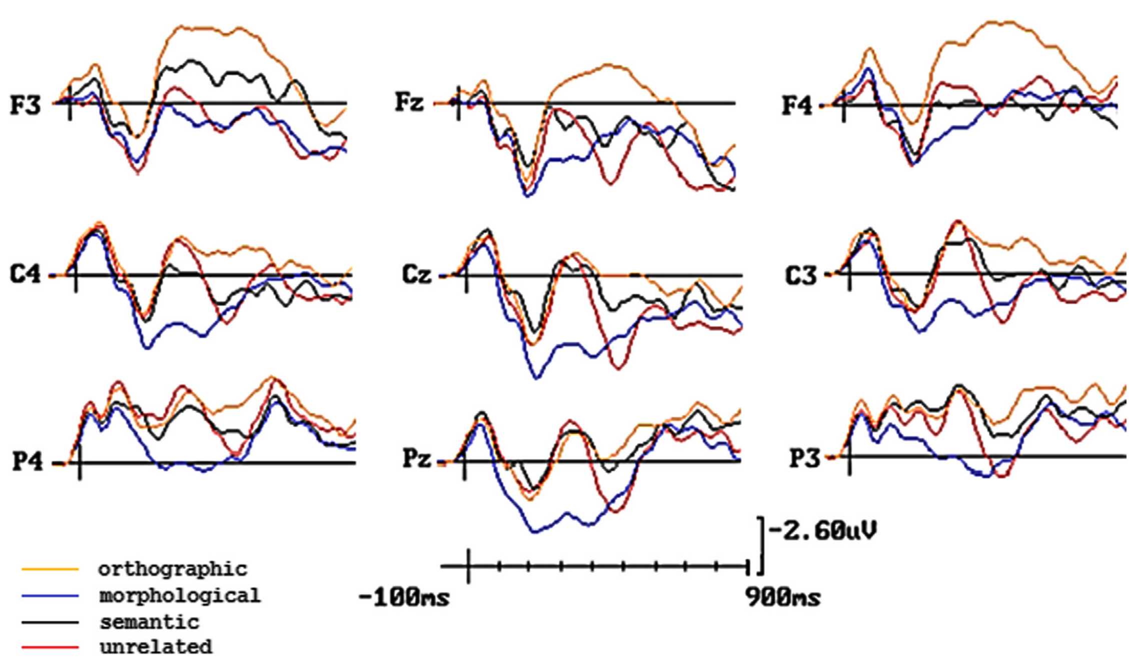

Fig. 1 – *Grand average ERPs*. **Grand average ERPs of correct lexical decisions to word targets, contrasting morphologically related, semantically related, orthographically related and unrelated prime–target pairs.**

decomposition at very early processing stages (e.g., Diependaele et al., 2011; Feldman et al., 2009).

Critically, while the majority of studies have examined semantic transparency contrasting morphological and pseudo-morphological priming (for a review, see Rastle and Davis, 2008), only few studies have directly compared morphological and semantic priming. In order to clearly explore whether or not semantics play a role during early morphological processing, it is necessary to use a priming condition in which primes and targets are semantically, but not morphologically or orthographically related. Behavioral investigations, which examined early versus late effects by using different prime durations (43 ms, 73 ms, and 230 ms), have revealed priming effects for morphologically related prime–target pairs at short prime durations but semantic priming effects only for longer prime durations (Rastle et al., 2000). However, it is not clear from behavioral data alone at what point in time semantic information has an impact on the processing of the target. In a priming study in Spanish, Dominguez et al. (2004, Experiment 3) addressed this problem using ERPs. Primes were presented for 300 ms and it was found that morphological and semantic priming differed in the earlier time frame (250–350 ms). However, differences between morphological and semantic priming (which visibly differed in the grand average waveforms) did not reach statistical significance in the later windows (350–450 ms and 450–600 ms). Questions thus remain regarding the onset of semantics during morphological processing. Moreover, since Dominguez et al. (2004, Experiment 3) did not use an orthographic prime condition within the same experiment, it is not entirely clear which components of the observed effects were due to orthographic similarities between the primes and the targets.

The goal of the present study was to further explore the time-course of semantic and morphological processing using ERPs, in a group of French participants. We conducted a primed lexical decision study comparing a morphological (*LAVAGE – laver* [*washing – wash*]), a semantic (*LINGE – laver* [*laundry – wash*]), an orthographic (*LAVANDE – laver* [*lavender – wash*]), and an unrelated control condition (*HOSPICE – laver* [*nursing home – wash*]). We are the first to use these four priming conditions within a single ERP-experiment. Our first aim was to explore whether *early* morphological priming effects are influenced by semantics or not. If it is true that the initial morphological processing stages are semantically blind (e.g., Longtin and Meunier, 2005; Rastle et al., 2004), we would expect a significant effect of morphological priming, but no effect of semantic priming in the earlier 100–250 ms time window. If, however, rapid access to semantic information can constrain the initial decomposition of words into morphemic subunits (e.g., Diependaele et al., 2011; Feldman et al., 2009), morphological priming and semantic priming should equally be present at 100–250 ms.

The second aim of the present study was to explore one aspect of morphological processing that has previously received very little attention: do priming effects in the transparent morphological condition arise due to a genuinely semantic relationship between the prime and the target or are they a consequence of the orthographic and semantic characteristics of truly affixed words? Recently, Diependaele et al. (2009) hypothesized that morphological processing has two different loci (see also Beyersmann et al., 2012). It was suggested that initial morphological processing is followed by a later 'morpho-semantic' processing stage, which uniquely applies to prime–target pairs sharing a morphological *and* semantic relationship, but not to pairs sharing a semantic relationship only. If this is true, we would expect that morphological and semantic priming should differ at the 250–450 ms time window (early N400). However, if the late morphological priming effects are due to a genuine semantic prime–target relationship rather than a specific morpho-semantic mechanism, we would expect no difference at 250–450 ms between the magnitudes of morphological and semantic priming.

Importantly, we designed our study such that the same target would be presented across all four conditions. One of the methodological shortcomings of previous morphological priming studies is that the critical comparisons (i.e., morphological, semantic, orthographic, unrelated) were made using target words that differed across conditions. It is therefore possible that differences across conditions might be due to uncontrolled differences between the target words (e.g., Perre et al., 2009). Given the sensitivity of ERPs (especially the early components) to physical differences between the items (e.g., Holcomb and Grainger, 2006; Petit et al., 2006), target-word differences likely produce variance in the results, which may be an important factor in explaining some of the inconsistencies in the literature. Finally, because it has been previously shown that semantic influences on morphological priming are more prominent when the prime becomes partially or fully visible (e.g., Lavric et al., 2011), we used prime presentation durations of 200 ms.

2. Results

2.1. *Behavioral results*

The error and reaction time data for the four conditions are presented in Table 1. The data were submitted to two analyses of variance (ANOVAs) with Prime Type (morphological, orthographic, semantic, unrelated) as a within-subject factor. On reaction times, the ANOVA yielded a significant effect of Prime Type ($F(3,54)=13.56$, $p<.001$, $\eta^2=.43$). We conducted a set of pairwise comparisons, correcting the level

Table 1 – Mean Reaction times (in ms) and error rates (in %) for each prime condition. Standard deviations are presented in parentheses.

Prime condition	Reaction times	Error rates	Example
Morphological	887 (64)	1.3 (2.8)	*LAVAGE – laver [washing – wash]*
Orthographic	942 (59)	4.5 (6.2)	*LAVANDE – laver [lavender – wash]*
Semantic	919 (42)	1.6 (3.4)	*LINGE – laver [laundry – wash]*
Unrelated	945 (46)	3.2 (3.8)	*HOSPICE – laver [nursing home – wash]*

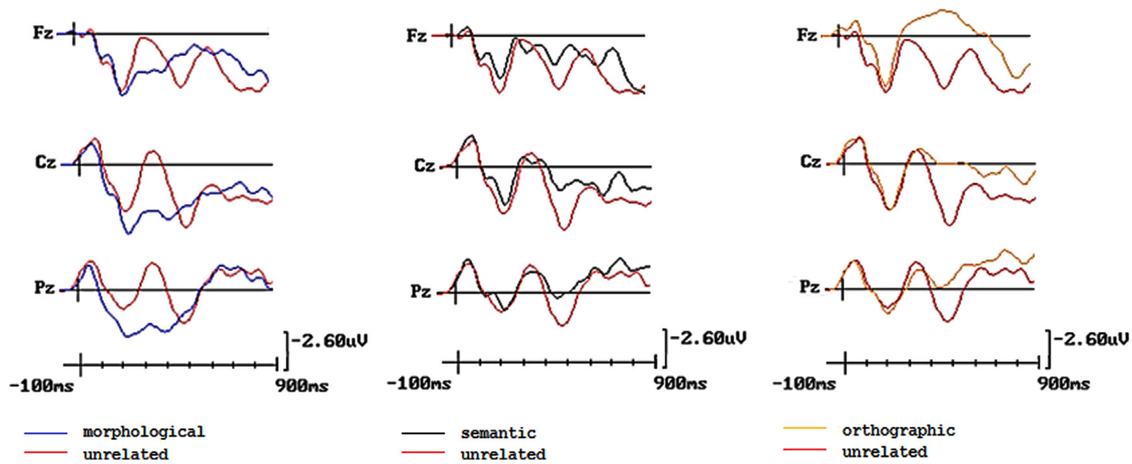

Fig. 2 – *Pairwise comparisons*. Pairwise comparisons of ERPs at central electrodes, contrasting related and unrelated prime–target pairs.

Table 2 – Summary of the ANOVA/MANOVA effects for each ERP interval. Uncorrected degrees of freedom, but corrected *p*-values are reported.

	N100 (0–100 ms)	P200 (100–250 ms)	Early N400 (250–450 ms)	LPC (450–500 ms)	Late N400 (500–650 ms)
Prime type	F(3,45)=.82; p=.49	F(3,45)=.96; p=.58	F(3,45)=13.21; p<.001	F(3,45)=6.32; p=.003	F(3,45)=3.75; p=.02
A/P location	F(2.30)=4.58; p=.03	F(2.30)=11.65; p<.001	F(2.30)=2.41; p=.13	F(2,30)=2.45; p=.13	F(2,30)=9.91; p<.001
Laterality	F(2.30)=1.69; p=.21	F(2.30)=11.25; p<.001	F(2.30)=8.66; p<.002	F(2,30)=8.54; p=.002	F(2,30)=8.25; p<.001
P × A/P	F(6.90)=2.57; p=.06	F(6.90)=2.69; p=.05	F(6.90)=2.16; p=.13	F(6.90)=2.41; p=.09	F(6.90)=.83; p=.55
P × L	F(6.90)=1.40; p=.25	F(6.90)=1.46; p=.23	F(6.90)=2.62; p=.06	F(6,90)=2.41; p=.04	F(6,90)=2.60; p=.06
A/P × L	F(4.60)=1.32; p=.27	F(4.60)=9.85; p<.001	F(4.60)=1.77; p=.17	F(4.60)=2.27; p=.10	F(4.60)=1.86; p=.13
P × A/P × L	F(12.180)=1.07; p=.39	F(12.180)=1.04; p=.39	F(12.180)=.72; p=.56	F(12.180)=1.22; p=.27	F(12.180)=.79; p=.79

P—priming; A/P location—anterior/posterior location; L—laterality.

of significance of each test using the Benjamini–Hochberg (BH) method (Benjamini and Hochberg, 1995).[1] The comparisons indicated a significant effect of morphological priming ($p<.001$; less than the BH-corrected threshold), a significant effect of semantic priming ($p<.001$; less than the BH-corrected threshold), and no significant effect of orthographic priming ($p=.776$). In addition, there was a significant difference between the morphological and orthographic priming condition ($p<.001$; less than the BH-corrected threshold), a significant difference between the morphological and semantic priming condition ($p=.012$; less than the BH-corrected threshold), but no significant difference between the semantic and orthographic priming condition ($p=.043$; greater than the BH-corrected threshold). The ANOVA performed on the error data revealed no significant effect of Prime Type ($F(3,54)=2.060$, $p>.10$, $\eta^2=.11$).

2.2. *Event-related potentials results*

Grand average ERPs of correct lexical decisions to word targets are presented in Figs. 1 and 2. The EEG data from three participants were excluded due to excessive ocular and movement artefacts. The data were analyzed in several time windows using factors Prime Type, Location, and Laterality (see Methods for further detail). A summary of the statistical results can be found in Table 2.

2.2.1. *0–100 ms (N100)*

The ANOVA on the mean N100 amplitudes revealed no significant effect of Prime Type or significant interactions with factor Prime Type.[2]

2.2.2. *100–250 ms (P200)*

The ANOVA on the mean P200 amplitudes indicated a main effect of Location ($F(2,30)=11.65$; $p<.001$, $\varepsilon=.69$) that significantly interacted with Prime Type ($F(6,90)=2.69$; $p=.04$, $\varepsilon=.56$).[3] The P200 amplitude that occurred for morphologically related targets was more positive than those for

[1]The BH-correction is a statistical method used in multiple hypothesis testing to correct for multiple comparisons (Benjamini and Hochberg, 1995).

[2]There was a main effect of Location ($F(2,30)=4.58$; $p<.03$, $\varepsilon=.83$). The N100 amplitude was less negative at frontal sites ($-.73\,\mu V$) than at both central ($-1.83\,\mu V$) and parietal sites ($-1.92\,\mu V$) (frontal vs. central, $p<.02$; frontal vs. parietal, $p<.01$; central vs. parietal, $p=.84$).

[3]The main effect of Laterality ($F(2,30)=11.25$; $p<.001$, $\varepsilon=.82$) and the interaction between Location and Laterality ($F(4,60)=9.85$; $p<.001$, $\varepsilon=.64$) were also significant. The P200 amplitude was more positive at both frontal ($1.38\,\mu V$) and central ($1.09\,\mu V$) sites than at parietal sites ($-1.02\,\mu V$) (frontal vs. parietal, $p<.001$; central vs. parietal, $p<.001$; frontal vs. central, $p=.59$) and to the right sided electrodes.

orthographically related targets at the three locations (frontal, $p < .001$; central, $p < .007$; parietal, $p < .001$) and it was more positive than those for unrelated targets at the central and the parietal locations (central, $p < .001$; parietal, $p < .01$). In contrast, the P200 amplitude for morphologically related targets was not significantly different from the P200 amplitude associated to semantically related targets at the frontal and central electrodes but it was slightly more positive going at the parietal locations as indicated by the marginally significant effect ($p = .07$). The effects found in the semantic, orthographic, and unrelated conditions did not differ. No other effects were significant.

2.2.3. 250–450 ms (early N400)

The ANOVAs on the mean N400 amplitudes exhibited significant main effects for Prime Type ($F(3,45) = 13.21$; $p < .001$, $\varepsilon = .80$) and Laterality ($F(2,30) = 8.66$; $p = .002$, $\varepsilon = .84$). The interaction between these two effects was marginally significant with corrected p values ($F(6,90) = 2.62$; $p = .06$, $\varepsilon = .51$) but reached significance with uncorrected p values ($p < .02$).

Morphologically related targets elicited a positive going potential (1.99 μV) which differed in amplitude from all other conditions (orthographically related $= -1.61$ μV; semantically related $= -.73$ μV; unrelated $= -.40$ μV, all $p < .001$). The laterality effect showed that the N400 amplitude was more negative at the two lateral sites (left $= -056$ μV; right $= -.95$ μV) than at the central sites (.94 μV) (left vs. right, $p = .69$; left vs. central, $p < .01$; right vs. central, $p < .001$). Unrelated targets exhibited a more negative N400 amplitude than semantically related targets (semantic priming effect) at left electrodes sites ($p = .003$). Orthographically related targets exhibited more negative N400 amplitude than semantically related targets at right electrodes sites ($p < .001$). Orthographically related targets exhibited more negative N400 amplitudes than unrelated targets at the left ($p < .001$), right ($p = .002$), and central ($p = .002$) electrodes sites. No other main effects or interactions reached significance.

2.2.4. 450–500 ms (late positive complex)

There was a significant main effect of Prime Type ($F(3,45) = 6.32$; $p < .003$, $\varepsilon = .74$), showing that orthographically related targets elicited a negative going potential (-2.09 μV) in contrast to the morphological (1.48 μV, $p = .002$), to the semantic (1.42 μV, $p = .027$), and to the unrelated condition (2 μV, $p < .001$), which did not significantly differ from one another on the averaged amplitudes (all p's > 1). However, the significant interaction between Prime Type and Laterality ($F(6,90) = 2.41$; $p < .04$, $\varepsilon = .57$) indicated that on the midline sites, the unrelated targets were associated with significantly higher positive amplitude than those elicited by all other targets (unrelated $= 3.88$ μV, morphologically related $= 2.74$ μV, orthographically related $= -.79$ μV, semantically related $= 2.65$ μV, unrelated vs. morphologically related, $p = .005$; unrelated vs. orthographically related, $p < .001$; unrelated vs. semantically related, $p = .003$).[4] No other effects were significant.

2.2.5. 500–650 ms (late N400)

There was a significant main effect of Prime Type ($F(3,45) = 3.75$; $p < .02$, $\varepsilon = .75$), showing that orthographically related targets were the only ones to elicit a sustained negative going potential (-1.30 μV) in contrast to all other targets which were associated with more positive potentials (orthographically vs. morphologically related, $p = .02$; orthographically vs. semantically related, $p < .001$; orthographically related vs. unrelated, $p < .001$), which did not significantly differ from one another (all p's > 1; morphologically related $= 1.23$ μV; semantically related $= 1.72$ μV; unrelated target $= 1.77$ μV).[5] No other effects were significant.

3. Discussion

The present study was designed to investigate the time-course of morphological as opposed to orthographic and semantic priming using the exact same targets across conditions. Our aim was to examine whether or not early and later morphological priming effects are influenced by semantics and test if N400 morphological priming effects arise due to a genuine semantic relationship between the prime and the target or are a consequence of the morpho-semantic characteristics of truly affixed words. This was achieved by contrasting semantic, morphological, and orthographic priming in the 100–250 ms, 250–450 ms, 450–500 ms, and 500–650 ms time windows, which were associated with different linguistic processes (Osterhout and Nicol, 1999).

In the behavioral data, there was a significant effect of morphological priming (e.g., *lavage – laver* [*washing – wash*]) and a significant effect of semantic priming (e.g., *linge – laver* [*laundry – wash*]). However, no priming was observed in the orthographic control condition (e.g., *lavande – laver* [*lavender – wash*]), suggesting that morphological priming cannot be explained by the orthographic prime–target relationship alone. In addition, the magnitude of morphological priming was significantly larger than the magnitude of semantic priming, indicating that morphological priming cannot be simply due to the semantic prime–target relationship. These findings provide a clear dissociation between morphological and semantic priming and point to a morphological processing mechanism which decomposes words with a genuine morphological structure into its morphemic constituents.

The ERP results showed that morphologically related word targets were associated with broad fronto-central positive going potentials which began to diverge from the ERPs to unrelated targets in the 100–250 ms time window. Although

[4]There was also a significant effect of Laterality ($F(2,30) = 8.54$; $p < .002$, $\varepsilon = .89$), showing that the ERP amplitudes at central sites (2.12 μV) were more positive than the amplitudes which occurred

(*footnote continued*)
on both lateral sites (left $= -.32$ μV, right $= .32$ μV: central vs. left, $p < .001$; central vs. right, $p = .006$; left vs. right, $p = .30$).

[5]There was also a main effect of Location ($F(2,30) = 9.91$; $p < .001$, $\varepsilon = .92$) and Laterality ($F(2,30) = 8.25$; $p < .001$, $\varepsilon = .90$). The ERP amplitudes were more positive on anterior (1.59 μV) and on central locations (2.48 μV) than on posterior ones (-1.47 μV) (anterior vs. posterior, $p = .003$; central vs. posterior, $p < .001$; anterior vs. central, $p = .35$). Moreover, midline amplitudes (2.54 μV) were larger than those which occurred on both lateral sites (left $= -.11$ μV, right $= .17$ μV) (midline vs. left, $p < .001$; midline vs. right, $p < .001$; left vs. right, $p = .70$).

the ERPs to morphologically related targets exhibited similar amplitudes as the semantically related targets, morphological priming was slightly more positive at the parietal locations. In addition, semantic priming did not reach significance in this early time window. The positive amplitudes of the ERPs which were associated with morphologically related targets were maintained through two later time windows (i.e. 250–450 ms and 450–600 ms). In the earlier N400 time window, ERPs to morphologically related targets were markedly more positive than those elicited by the other conditions which were all characterized by more negative-going potentials. However, in the later time windows (450–500 ms and 500–650 ms), only orthographically related targets were associated with negative-going potentials, in contrast to morphologically related, semantically related, and the unrelated word targets which were all associated with positive-going potentials.

The positive potentials between 100–250 ms (the P200) are generally considered to be sensitive to processing at the level of visual features and orthographic prime–target overlap (e.g., Kiyonaga et al., 2007; Petit et al., 2006). However, in our study, the positivity of the P200 cannot be merely attributed to letter overlap between the prime and the morphologically related target because orthographically related targets did not elicit comparable positive going potentials. Critically, while there was a robust effect of morphological priming, no evidence for semantic priming was observed in this early time window. In the later 250–450 ms time window however, we observed a right lateralized N400 priming effect in the semantic condition. However, this priming effect did not reach the same amplitude as the morphological priming effect and was only found at left lateralized electrodes. These results challenge theories suggesting that semantics influence early morphological processing (e.g., Diependaele et al., 2011; Feldman et al., 2009). Our findings appear to be more consistent with theories proposing that early morphological priming is semantically blind, as previously evidenced by equal magnitudes of priming for morphologically (e.g. *walker* – *WALK*) and pseudo-morphologically related (e.g. *corner* – *CORN*) prime–target pairs (Lavric et al., 2007, 2012, 2011; Morris et al., 2007).

In the classical N400 window, orthographically related, semantically related, and unrelated word targets exhibited a standard N400, whereas the morphologically related targets exhibited a reduced N400 amplitude, which significantly differed from all other conditions. This result is consistent with previous studies which reported a robust N400 morphological priming effect (e.g., Dominguez et al., 2004, 2006; Lavric et al., 2007, 2011; Morris et al., 2007). Our results support the conclusion that the semantic integration between the prime and the target is facilitated when they share the same morpheme and that this morphological priming is specific and robust even when the *same* target words are used across conditions (which eliminates potentially uncontrolled differences between target words that could explain some of the differences found in previous studies).

Critically, although it was methodologically impossible to perfectly match the number of shared letters (orthographic overlap) across the orthographic and morphological condition, it seems highly unlikely that this accounts for the observed morphological priming effects. In fact, orthographically related targets were associated with more negative-going potentials, in contrast to all other three conditions. Thus, if priming in the morphological condition was due to the increased orthographic prime–target overlap in this condition, we would expect, if anything, that priming in this condition should be reduced, which was not the case in the present data. Hence, given the absence of a N400 attenuation in the orthographic condition, it can be ruled out that the effect observed in the morphological condition was simply due to orthographic prime–target overlap and/or an additive effect of morphological and orthographic priming. Most importantly, the present data show a clear dissociation between the N400 morphological priming effect and semantic priming. This suggests that the morphological N400 priming effect is not simply a result of semantic facilitation between the prime and the target and thus demonstrate that the obtained effect reflects a process of morphological segmentation, which is thought to decompose all words into their morphological constituents.

One explanation for our findings is that N400 priming for morphologically structured items arises as a result of the shared representations of morphological neighbors at a specific morpho-semantic processing level, and not because of shared orthography or semantics. This is in line with a hypothesis proposed earlier (e.g., Beyersmann et al., 2012; Diependaele et al., 2005, 2009), suggesting that the morphological structure of printed words is represented at two distinct levels: (i) at an early sublexical level where morphologically complex words are decomposed into orthographically defined morphemic units, and (ii) at a later supralexical level where morphologically complex words are decomposed into semantically defined morphemic units. An alternative explanation is that the greater priming in the morphological condition reflects a summation of an earlier morpho-orthographic effect which cascades into the later processing stages (as it has also been evidenced in previous research, e.g. Lavric et al., 2007) and semantic priming. Critically however, the absence of semantic priming in this time-window challenges the latter hypothesis.

Interestingly, orthographically related targets exhibited more negative N400 amplitudes than unrelated and semantically related targets in the 250–450 ms time window, which became more prominent in the later time windows. In the 450–500 ms and 500–650 ms time windows, we observed that all ERP components became positive, whereas the amplitudes associated with orthographically related targets remained negative. This indicates that the N400 for morphologically related, semantically related and unrelated targets was definitively resolved after the 250–450 ms time interval. Critically, the long-lasting negativity in the orthographic condition may be interpreted as the consequence of an inhibitory effect for orthographically related words that delays the integration of meaning. This is consistent with the findings of Holcomb et al. (2002) who reported larger N400 amplitudes for words with many orthographic neighbors as opposed to words with few orthographic neighbors in both lexical decision and semantic categorization. One explanation for this finding is that the activation of an orthographically similar prime leads to strong competition between the target and the prime because they share orthographic form but not meaning. The presentation of the target might actually boost the activation of the (visible) prime and the competition between these two strongly activated orthographic neighbors needs to be resolved, which is indicated in increased N400 amplitudes. By contrast, such competitive inhibitory effects do not arise for morphologically related prime–target pairs, because primes and targets do not only share orthographic but also morpho-semantic representations, thus producing facilitatory priming.

Finally, in the 450–500 ms interval, the significant interaction between Prime Type and Laterality (Table 2) showed that at midline electrodes, the unrelated condition exhibited a significantly larger positive peak compared to the other three conditions. This late positive complex (LPC) is in line with evidence frequently reported in the literature from semantic priming tasks (for a review, see Kuperberg, 2007). Given the frequent temporal and spatial overlap between the N400 and LPC, the functional relationship between these two components is difficult to determine (Curran et al., 1993). Some authors argue that the N400 and LPC reflect discrete processes (Van Petten et al., 1991), but others suggest that they reflect different phases of the same general integrative mechanisms (Halgren, 1990). The LPC is related to a more general process of attention and decision making, successful comprehension (Coulson and Kutas, 2001), and "confidence with judgment" (McCallum et al., 1989). Van Petten et al. (1991) also suggest that the LPC indexes "the extended retrieval of semantic and episodic information and the integration of that information with the contexts of working memory" (p. 145).

In conclusion, the present study shows remarkably robust morphological priming effects both at early and at later time windows. The robustness of these results can be explained by two factors: firstly, identical targets were used across all priming conditions which reduce the variability in response to different targets. Secondly, the present study was conducted in French, a language which, compared to English, is known to have a particularly rich and productive derivational morphology. Taken together, the present data do not only reveal that the early stages of morphological processing are semantically blind, but also demonstrate that the later stages of morphological processing can be clearly dissociated from semantic processing, which is in line with the hypothesis that morphologically complex words are decomposed into morpho-semantic subunits during reading.

4. Experimental procedures

4.1. *Participants*

Nineteen healthy, native French-speaking volunteers (9 females, 10 males) participated in this study and were paid for their participation. Their ages ranged from 19 to 50 years (mean=31.8; σ=10.2). All were all right-handed, with normal or corrected or corrected-to-normal vision and none reported any neurological or language impairment. All participants were volunteers and gave written consent. The study was approved by the local ethics committee.

4.2. *Materials*

320 Prime–target pairs were selected from the LEXIQUE database (http://www.lexique.org/), and divided into four sets of 80 pairs each: (1) morphologically related (*LAVAGE – laver* [*washing – wash*]), (2) semantically related (*LINGE – laver* [*laundry – wash*]), (3) orthographically but not semantically or morphologically related (*LAVANDE – laver* [*lavender – wash*]), and (4) unrelated (*HOSPICE – laver* [*nursing home – wash*]). Prime words were presented in upper case, whereas target words were presented in lower case. In the morphologically related condition, primes and targets belonged to the same morphological family. Targets had a mean length 5.32 letters (SD=1.08) and a mean frequency of 54.83 (SD=87.11) per million according to LEXIQUE. Table 3 presents the main item characteristics in the four experimental conditions. Across the four conditions, the primes were matched in terms of frequency (all $p>.50$), number of letters (all $p>.15$), and number of syllables (all $p>.12$). In order to control the strength of the semantic association between the morphological and the semantic condition, we calculated the semantic similarity between primes and targets using latent semantic analysis (LSA, http://lsa.colorado.edu/). There was no difference ($p>.78$) in semantic association strength between the morphological (mean=.37; SD=.23) and the semantic conditions (mean=.36; SD=.18). Since the same targets were used across different prime conditions, it was impossible to perfectly match for orthographic prime–target overlap across conditions. In the morphological condition, targets and primes had on average 4.27 letters in common (SD=1.15), while in the orthographic condition they shared on average 3.12 letters (SD=.82), and this difference was significant (t=4.502; $p<.001$).

The items were divided into four lists, containing 20 prime–target pairs from each condition, such that participants would never see the same target twice. Each subject saw each target only once. For the purposes of the lexical decision task, we included 80 pronounceable nonword targets preceded by word primes. Nonwords were formed by changing two letters from a real word.

4.3. *Procedure*

Each trial consisted of the presentation of a fixation cross displayed in the center of the monitor. 200 ms after its onset,

Table 3 – Characteristics of primes across different prime conditions. Standard deviations are presented in parentheses.

Properties	Type of prime			
	Morphological	Orthographic	Semantic	Unrelated
Frequency	13.12 (21.07)	14.91 (26.98)	15.16 (16.93)	15.03 (27.18)
Length	6.97 (1.16)	7.05 (.86)	6.8 (1.31)	7.02 (.83)
Number of syllables	2.13 (.44)	2.05 (.35)	2 (.66)	2.05 (.35)

a prime was presented for 200 ms. Target words were presented for 200 ms, 50 ms after the offset of the prime (stimulus-onset asynchrony was 250 ms). Participants were asked to press the left button with the right index finger when the target was a word and the right button if it was not a word. The next trial appeared 1900 ms after the offset of the target word.

4.4. *ERP recordings and data analyses*

Electroencephalogram (EEG) recordings were performed with a REEGA 2000 apparatus and an InstEP interface program for ERP data acquisition. Twelve Ag/AgClelectrodes were arranged on subjects' scalps according to international standards (10–20 system; Jasper, 1958). Three electrodes were placed in the frontal region (F3, Fz, F4), three were placed in the central region (C3, Cz, C4), three were placed in the parietal region (P3, Pz, P4), one was placed in the left temporal region (T3), one was placed in the right temporal region (T4), and one electrode was placed at the occipital midline (Oz). Four additional electrodes were used to record eye movements (EOGs). Two electrodes were placed in the vicinity of the external canthus, one electrode was placed above the eye, and one electrode was placed below the eye. Reference electrodes were connected to the ear lobes. All impedances were kept below 1.8 kΩ. EEGs were continuously recorded using the InstEP system at a frequency of 512 points/ sec with an initial bandwidth of .15–60 Hz. Single trials exceeding $\pm 100\ \mu V$ were rejected (mean percentage of rejected trials was 1.9%). The remaining trials were corrected off-line for the effects of eye blinks and eye movements by means of an automatic program. The data were digitally filtered at a bandwidth of .1–20 Hz.

The mean amplitude of the ERP components elicited by each correctly identified target word were determined as signed deviations from the baseline and were quantified as the mean of the voltage at each electrode relative to a 100 ms pre-stimulus baseline over a 0–100 ms post-stimulus onset (N100) time interval, a 100–250 ms post-stimulus onset, a 250–450 ms post-stimulus onset time interval, and a 450–650 ms post-stimulus onset time interval. The magnitude of priming was measured by comparing the amplitude of the morphological, orthographic, and semantic component to the amplitude of the unrelated condition.

The ERP analyses were restricted to correct lexical decision responses and to nine representative electrodes sites distributed across the scalp (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4). To analyze the scalp distribution of the ERP effects, we included a factor Location representing anterior/posterior distribution contrasting electrode locations from the front to the back of the head (frontal vs. central vs. parietal locations), and a second factor "Laterality" representing left/right distribution contrasting electrode location at left, center and right side of the head. The mean ERPs amplitudes obtained in each time window were analyzed using separate repeated-measures analyses of variance (ANOVAs) and three within-subject factors: prime type (morphologically-semantically related, orthographically related, semantically related, unrelated), location, and laterality.

Acknowledgments

The authors gratefully acknowledge the support of the Fondation Fyssen through a Post-doctoral grant awarded to Elisabeth Beyersmann. Part of this research was supported by the Center of Excellence on Brain and Language (Labex BLRI, ANR-11-LABX-0036) managed by the French National Agency for Research (ANR), Investments of the Future A*MIDEX (ANR-11-IDEX-0001-02).

Appendix 1

Item	Prime				Target
	Morphological	Orthographic	Semantic	Unrelated	
1	acheter	achever	cadeaux	taillis	achat
2	amoureux	amuser	baiser	occupé	amour
3	arrosoir	arrogance	pelouse	camembert	arroser
4	baigner	baisser	détente	caserne	bain
5	balayer	balance	sorcière	faïence	balai
6	banquier	banlieue	sécurité	mensonge	banque
7	bataille	bateaux	soldat	haleine	battre
8	buvette	boiteux	auberge	gobelet	boire
9	bricolage	brigade	outil	insecte	bricoler
10	brosser	brochet	peigne	fournil	brosse
11	brûlure	brusque	urgence	muscles	brûler
12	bûcheron	bucolique	flambée	carnivore	bûche
13	cafetière	carottes	chocolat	bulletin	café
14	calculer	calcaire	math	séquelle	calcul
15	cendrier	central	mégots	fantôme	cendre
16	cerisier	cerceau	gâteau	rancard	cerise

17	chanteur	chantage	musicien	paupière	chant
18	chaton	chatouille	miauler	roquefort	chat
19	chemisier	cheminot	vêtement	diapason	chemise
20	chienne	chimie	aboyer	bitume	chien
21	cirage	circuler	chaussures	évangile	cirer
22	clochette	clonage	pâques	besogne	cloche
23	clouer	cloison	pointu	tumulte	clou
24	coiffeur	collier	poupée	diamant	coiffer
25	coller	collège	affiche	tromper	colle
26	compter	complet	chiffres	sergent	compte
27	couture	couchette	tissus	ressource	coudre
28	coupure	couplet	légume	laurier	couper
29	criée	cristal	hurler	retrait	crier
30	cuisson	cuiller	cuisiner	soutien	cuire
31	danseur	dangereux	bouger	troisième	danser
32	fermier	femelle	campagne	licence	ferme
33	fermeture	ferveur	entrée	estrade	fermer
34	fleuriste	fleuret	abeille	potence	fleur
35	gardien	garage	prisonnier	profit	garder
36	glacier	glander	vanille	suicide	glace
37	gommer	goudron	effacer	parrain	gomme
38	grimper	grimace	échelle	baraque	grimper
39	grossir	grogner	maigrir	algèbre	gros
40	jouet	joufflu	déguiser	missive	jouer
41	lavage	lavande	linge	hospice	laver
42	légère	légende	plume	soupir	léger
43	lenteur	leçons	vieillard	emploi	lent
44	levée	lequel	coucher	vipère	lever
45	logement	logique	loyer	torrent	loger
46	maîtresse	maigres	élève	disques	maître
47	malade	machine	hôpital	papiers	mal
48	mallette	malaria	grenier	laxatif	malle
49	mouillage	moulins	pleuvoir	arnaque	mouiller
50	mural	murmure	briques	tempête	mur
51	nageur	naguère	plongée	modeste	nager
52	noisette	noircir	coco	pelisse	noix
53	oranger	orages	citron	hublot	orange
54	oreiller	ordures	ouïe	méthode	oreille
55	osseux	oseille	squelette	châssis	os
56	ourson	oursin	peluche	gésier	ours
57	passage	passion	examen	tourner	passer
58	pécheur	pétards	barques	caleçon	péche
59	peinture	pensées	tableau	étoiles	peindre
60	percée	perchoir	trouer	archange	percer
61	pesée	peste	kilo	berge	peser
62	pincer	pinède	épiler	besace	pince
63	piqûre	pirates	moustique	sultane	piquer
64	pommier	pommade	poire	charpie	pomme
65	portier	portrait	intérieur	assiette	porte
66	poulet	poulain	mouillée	monocle	poule
67	prunier	prunelle	violet	mercière	prune
68	ramer	rameau	aviron	coquet	rame
69	rasoir	rasade	poilu	patate	raser
70	rosier	roseau	pétale	ermite	rose
71	saladier	salami	composée	kimono	salade
72	sauter	sauvage	athlète	miracle	saut
73	savonner	savant	propreté	jockey	savon
74	scier	scooter	barreau	quignon	scie
75	serveur	serviette	boisson	enveloppe	servir
76	siffler	sillage	policier	cantine	siffler

77	sonnette	songer	alarme	fracas	sonner
78	tiroir	timide	ficelle	étoffe	tirer
79	vendeur	venger	marchandise	copine	vendre
80	voilier	voiture	bateau	travail	voile

REFERENCES

Barber, H., Dominguez, A., De Vega, M., 2002. Human brain potentials indicate morphological decomposition in visual word recognition. Neurosci. Lett. 318, 149–152.

Benjamini, Y., Hochberg, Y., 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. J. R. Stat. Soc., Ser. B 57 (1), 289–300.

Beyersmann, E., Castles, A., Coltheart, M., 2011. Early morphological decomposition during visual word recognition: evidence from masked transposed-letter priming. Psychon. Bull. Rev. 18 (5), 937–942.

Beyersmann, E., Coltheart, M., Castles, A., 2012. Parallel processing of whole-words and morphemes in visual word recognition. Quart. J. Exp. Psychol. 65 (9), 1798–1819.

Coulson, S., Kutas, M., 2001. Getting it: human event-related brain response to jokes in good and poor comprehenders. Neurosci. Lett. 316 (2), 71–74.

Curran, T., Tucker, D.M., Kutas, M., Posner, M.I., 1993. Topography of the N400: brain electrical activity reflecting semantic expectancy. Electroencephalogr. Clin. Neurophysiol. 88, 188–209.

Diependaele, K., Duñabeitia, J.A., Morris, J., Keuleers, E., 2011. Fast morphological effects in first and second language word recognition. J. Mem. Lang. 64, 344–358.

Diependaele, K., Sandra, D., Grainger, J., 2005. Masked cross-modal morphological priming: unravelling morpho-orthographic and morpho-semantic influences in early word recognition. Lang. Cognit. Process. 20 (1–2), 75–114.

Diependaele, K., Sandra, D., Grainger, J., 2009. Semantic transparency and masked morphological priming: the case of prefixed words. Mem. Cognit. 37, 895–908.

Dominguez, A., Alija, M., Cuetos, F., de Vega, M., 2006. Event related potentials reveal differences between morphological (prefixes) and phonological (syllables) processing of words. Neurosci. Lett. 408 (1), 10–15.

Dominguez, A., De Vega, M., Barber, H., 2004. Event-related brain potentials elicited by morphological, homographic, orthographic, and semantic priming. J. Cognit. Neurosci. 16 (4), 598–608.

Feldman, L.B., O'Connor, P.A., Moscoso del Prado Martin, F., 2009. Early morphological processing is morpho-semantic and not simply morpho-orthographic: a violation of form-then-meaning accounts of word recognition. Psychon. Bull. Rev. 16 (4), 684–691.

Halgren, E., 1990. Insights from evoked potentials into the neuropsychological mechanisms of reading. In: Scheibel, A.B., Wechsler, A.F. (Eds.), Neurobiology of Higher Function. Guilford Press, New York, pp. 103–150.

Holcomb, P.J., Grainger, J., 2006. On the time-course of visual word recognition: an ERP investigation using masked repetition priming. J. Cognit. Neurosci. 18 (10), 1631–1643.

Holcomb, P.J., Grainger, J., O'Rourke, T., 2002. An electrophysiological study of the effects of orthographic neighborhood size on printed word perception. J. Cognit. Neurosci. 14, 938–950.

Jasper, H.A., 1958. The ten–twenty system ofthe International Federation. Electroencepholgr. Clin. Neurophysiol. 10, 371–375.

Kiyonaga, K., Grainger, J., Midgley, K.J., Holcomb, P.J., 2007. Masked cross-modal repetition priming: an event-related potential investigation. Lang. Cognit. Process. 22 (3), 337–376.

Kuperberg, G.R., 2007. Neural mechanisms of language comprehension: challenges to syntax. Brain Res. 1146, 23–49.

Lavric, A., Clapp, A., Rastle, K., 2007. ERP evidence of morphological analysis from orthography: a masked priming study. J. Cognit. Neurosci. 19, 866–877.

Lavric, A., Elchlepp, H., Rastle, K., 2012. Tracking hierarchical processing in morphological decomposition with brain potentials. J. Exp. Psychol.: Hum. Percept. Perform. 38 (4), 811–816.

Lavric, A., Rastle, K., Clapp, A., 2011. What do fully visible primes and brain potentials reveal about morphological processing?. Psychophysiology 48, 676–686.

Lewis, G., Solomyak, O., Marantz, A., 2011. The neural basis of obligatory decomposition of suffixed words. Brain Lang. 118, 118–127.

Longtin, C.M., Meunier, F., 2005. Morphological decomposition in early visual word processing. J. Mem. Lang. 53, 26–41.

Longtin, C.M., Segui, J., Hallé, P.A., 2003. Morphological priming without morphological relationship. Cognit. Process. 18, 313–334.

McCallum, W.C., Barrett, K., Pocock, P.V., 1989. Late components of auditory-event-related potentials to eight equiprobable stimuli in a target detection task. Psychophysiology 26, 683–694.

Morris, J., Frank, T., Grainger, J., Holcomb, P.J., 2007. Semantic transparency and masked morphological priming: an ERP investigation. Psychophysiology 44, 506–521.

Morris, J., Grainger, J., Holcomb, P.J., 2008. An electrophysiological investigation of early effects of masked morphological priming. Lang. Cognit. Process. 23 (7/8), 1021–1056.

Morris, J., Grainger, J., Holcomb, P.J., 2013. Tracking the consequences of morpho-orthographic decomposition using ERPs. Brain Res. 1529, 92–104.

Morris, J., Porter, J.H., Grainger, J., Holcomb, P.J., 2011. Effects of lexical status and morphological complexity in masked priming: an ERP study. Lang. Cognit. Process. 26 (4–6), 558–599.

Osterhout, L., Nicol, J.L., 1999. On the distinctiveness, independence, and time course of the brain responses to syntactic and semantic anomalies. Lang. Cognit. Process. 14, 283–317.

Perre, L., Midgley, K., Ziegler, J.C., 2009. When beef primes reef more than leaf: orthographic information affects phonological priming in spoken word recognition. Psychophysiology 46 (4), 739–746.

Petit, J.P., Midgley, K.J., Holcomb, P.J., Grainger, J., 2006. On the time-course of letter perception: a masked priming ERP investigation. Psychon. Bull. Rev. 13 (4), 674–681.

Rastle, K., Davis, M.H., 2008. Morphological decomposition based on the analysis of orthography. Lang. Cognit. Process. 23, 942–971.

Rastle, K., Davis, M.H., Marslen-Wilson, W., Tyler, L.K., 2000. Morphological and semantic effects in visual word recognition: a time-course study. Lang. Cognit. Process. 15 (4–5), 507–537.
Rastle, K., Davis, M.H., New, B., 2004. The broth in my brother's brothel: morpho-orthographic segmentation in visual word recognition. Psychon. Bull. Rev. 11, 1090–1098.
Solomyak, O., Marantz, A., 2009. Evidence for early morphological decomposition in visual word recognition. J. Cognit. Neurosci. 22 (9), 2042–2057.
Solomyak, O., Marantz, A., 2010. MEG evidence for early morphological decomposition in visual word recognition: a single-trial correlational MEG study. J. Cognit. Neurosci. 22, 2042–2057.
Van Petten, C., Kutas, M., Kluender, R., Mitchinier, M., McIsaac, H., 1991. Fractionating the word repetition effect with event-related potentials. J. Cognit. Neurosci. 3, 131–150.