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Event-related brain potentials of masked repetition and semantic priming while listening to sentences

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HIGHLIGHTS

- We combined for the first time ERPs and masked priming in sentential context.
- We found that sentence context influences priming effects in two ways.
- Semantic and repetition priming show the same N400-attenuation.
- Repetition priming evokes an additional late positive deflection (LPC).
- We show that word recognition in sentential context differs from list presentation.

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ABSTRACT

We combined for the first time electrophysiological measures and masked priming technique in sentential context, by setting up a cross-modal masked priming paradigm involving the auditory presentation of sentences. ERPs were time-locked to an auditorily presented word that was preceded by a repeated, related or unrelated pattern masked prime. We registered a two-way N400-difference between unrelated and related/repeated primes, followed by a late positive component (LPC) for repetition priming. Related primes appear to facilitate the lexical-semantic processing of the target to the same extent repeated primes do (equally attenuated N400). Repetition priming exerts additional demands (LPC), possibly related to enhanced recollection or to the construction of a discourse representation. This evidences that the sentential context interacts with masked priming in two vital ways, differing from word list contexts, and paves the way for future studies on the mechanisms of lexical/semantic processes beyond the word level.

1. Introduction

The combination of rapid masked priming of words with the recording of event-related brain potentials (ERPs) has been used to investigate temporal aspects of word recognition and to identify factors involved in early semantic processing. This combination has been a fruitful endeavor revealing early effects of orthographic, phonological, and semantic similarity, among others, during word recognition, reflected by a series of electrophysiological measures starting as early as 100 ms after the presentation of a target [3,6]. A central-parietal negativity peaking around 400 ms post-target (N400) has been shown to be sensitive to semantic information and reflects the strength of semantic associations between prime and target word [6,12]. Given its value in exploring semantic processing, this methodology appears to be a promising approach also for investigations of meaning construction beyond the word level and to assess the role of discrete lexical elements and semantic features during combinatorial processes. Prior ERP investigations targeting language processing have utilized masked priming in word lists, but to explore phenomena beyond the word, it is essential to prime information presented in sentences or texts. The current research therefore sought to investigate whether masked repetition and semantic priming in sentential context evokes ERP-signatures similar to those observed in word lists in order to set up the methodological basis for future research on sentence and text comprehension.

ERP-measures in both masked and unmasked paradigms on word lists have revealed that repetition priming and semantic/

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associative priming are reflected in N400-modulations, showing a three-way gradation of the N400-amplitude as a function of the prime's associative strength (unrelated > related > repeated). Repeated words typically evoke attenuated N400-amplitudes compared to unrelated words both in masked and unmasked lists [9,14,18,19]. The findings for semantically related masked words typically produced N400-amplitude differences between related and unrelated target words [4,11]. The amplitudinal attenuation observed for repeated and related primes has been taken to reflect facilitated access of the lexical representation of the target due to the associative relation between prime and target.

In order to test priming effects in sentential contexts, we opted for a cross-modal presentation of prime and target in the current investigation. Behavioral measures have already confirmed the effectiveness of cross-modal priming paradigms in lists and sentence contexts, both masked [2] and unmasked [22]. Electrophysiological evidence comes from unmasked [5] and masked cross-modal priming in list paradigms [13]. Kiyonaga et al. [13] showed in an ERP study that masked repetition priming effects are reliably produced in word lists with visual display of primes and subsequent auditory presentation of targets, observing a pronounced N400 for unrelated primes compared to repeated primes. The latency of the N400 was comparable to within modality procedures with a prime duration of 67 ms, but was delayed at shorter prime durations. Here and in other studies, it has been demonstrated that the size and latency of the masked priming ERP effect is contingent on prime duration, type of mask and other parameters [7,8,13].

The current experiment utilized a cross-modal pattern masked priming paradigm, where the auditorily presented target was included in a short sentence and a visual pattern masked prime, which represented either a repeated, related or unrelated prime, was presented 100 ms before target-onset. Our goal was to assess the influence of masked priming during sentence comprehension. If it is context-independent, the degree of semantic association between target and prime will modulate the N400-amplitude as previously observed for word lists, i.e., with a three-way gradation.

2. Material and methods

Forty-three native speakers of German (29 women, 14 men, average age: 24.6 years) entered the analysis. All were right-handed and reported no history of neurological disorder. Ninety sets of stimuli were created, which were designed in triplets, consisting of a sentence containing the target word (e.g., *Vortrag* ("talk") in *Ein Student besuchte neulich einen Vortrag in Berlin* ("Lately, a student attended a talk in Berlin")) and three different primes varying in semantic association strength with the target (repeated: *Vortrag* ("talk"), related: *Redner* ("speaker"), unrelated: *Schneider* ("tailor")). Related prime-target pairs represented either associated pairs (*talk/speaker*) or part-whole relations (*cup/handle*). Relatedness had been assessed in previous studies [1,21]. Primes across conditions were matched for frequency (*Deutscher Wortschatz, Leipzig*) and length. The unrelated primes were selected from the existing primes by random reallocation, allowing us to balance frequency and length differences across primes. The 270 experimental stimuli were distributed across three lists, interspersed with 198 fillers, and presented in a pseudorandomized order. 60% of the filler items were presented only with pattern masks and no prime.

We employed a cross-modal pattern masked priming paradigm, in which sentences containing the target words were presented auditorily and the primes were presented visually 100 ms before the target. ERPs were recorded and time-locked to the word recognition point of the target (see below). Participants were required to perform two tasks: a color change detection task targeting the pattern mask, which assured that participants were attending to the visual display without explicitly mentioning masked priming to them, and a probe recognition task, which encouraged participants to listen to the sentences attentively.

Participants sat in a soundproof cabin and were instructed to listen to the sentences while looking at a monitor. The visual material was presented in the middle of the black screen in off-white letters. Fig. 1 depicts a sample trial. Each trial began with a fixation star (500 ms). Then a forward mask (##########) was displayed, and the presentation of the auditory sentence started. 100 ms before the onset of the target word, the prime was presented for a duration of 67 ms and immediately replaced by a backward mask (XXXXXXXXXXX) which stayed on the monitor till the end of the auditory presentation. After a blank screen (1500 ms), a question mark signaled participants to indicate whether they had observed a color change on the screen by pressing one of two buttons on a game pad. In 44.4% of the trials the forward mask changed the color from off-white to blue for a short duration of 100 ms. To guarantee that the color change did not have a direct impact on the interval recorded for present purposes, it occurred on the forward mask well before the critical target word was heard (>1000 ms). Another blank screen (1500 ms) preceded the visual presentation of the probe recognition task, which tested a random word from the auditory input in 50% of the cases; the visual prime was probed in 22% of the cases and assumed to not be recognized. After an intertrial interval (1500 ms), the next trial was presented.

Following EEG recording, participants performed a prime detection task containing thirty masked primes used in the experiment, but without any targets. Each trial was 4000 ms long and included the forward mask, presented for 900 ms or 1900 ms to avoid predictability, followed by the prime for 67 ms and the backward mask. Participants were asked to name the word they had just seen

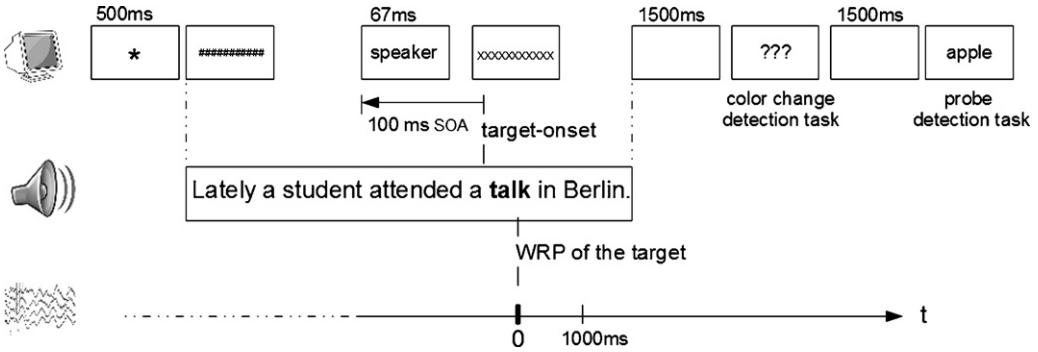

Fig. 1. Schematic illustration of the stimulus presentation during cross-modal masked priming task for an auditory stimulus combined with a visual probe ("speaker") and an unrelated probe recognition task ("apple"). Duration of the masks depends on length of the auditory stimulus. ERPs are time-locked to the word recognition point (WRP). SOA: stimulus onset asynchrony.

between the masks or indicate that they had not detected a word. This task was utilized to assess the masked prime recognition rates.

The electroencephalogram was recorded from 26Ag/AgCl scalp electrodes mounted in an elastic cap (ground: AFz). Electrodes were referenced to the left mastoid and rereferenced offline to linked mastoids. Four electrodes were placed around the eyes to control for eye movement artifacts. All channels were recorded using a *BrainVision Brain-Amp* amplifier and digitized at a rate of 500 Hz. Impedances were kept below 4 kΩ. Data were bandpass-filtered offline (0.3–20 Hz). Trials with ocular artifacts (cutoff point: ±40 μV; 16%) and with false responses to the probe recognition task (5%) were removed. ERPs were then averaged per participant, condition and electrode for a time window from 200 ms prior to the recognition point of the critical word to 1000 ms after. Grand-averages were then computed over all participants and repeated-measures analyses of variance (ANOVAs) were carried out with the factor RELATEDNESS and three levels (unrelated/related/repeated) for mean amplitude values in time-windows predetermined by visual inspection. The statistical analysis of the ERP data was computed separately for midline (Fz/FCz/Cz/CPz/Pz/POz) and lateral channels (F3/F4/F7/F8/FC1/FC2/FC5/FC6/C3/C4/T7/T8/CP1/CP2/CP5/CP6/P3/P34/P7/P8). Pair-wise comparisons were calculated with an adjusted significance level set to $p < .03$ based on a modified Bonferroni procedure [10].

The ERPs were time-locked to the word recognition point of each target word. This decision was guided by findings from spoken language perception showing that ERP-signatures like the N400 varied for words with early and late word recognition points [15,23]. In order to avoid a confounding influence of varying word identification points, we determined the recognition point for each item in order to compute ERPs relative to this point. This was done through a gating task on six native speakers of German who had not been exposed to the materials previously. The gate that evoked the majority of correct recognitions was chosen as word recognition point for each word individually. The mean latency of the recognition points was 185 ms (SD: 97 ms) after the onset of the target word. Fig. 2 illustrates the differences between time-locking to word onset (left panel) and to the word recognition point (right panel).

3. Results

High accuracy rates were obtained in the color detection (87%) and the probe recognition task (95%), indicating that participants were properly attending to both the visual display and the auditory stimuli. Fig. 3 depicts the grand-average ERPs for the three different prime-target combinations. The unrelated condition evoked a more pronounced negativity between 240 and 360 ms after the target's recognition point, relative to the related and repeated conditions, which did not differ from each other. In addition, the repeated condition showed a pronounced positive deflection between 400 and 700 ms.

For the time-window between 240 and 360 ms (N400), the statistical analyses revealed a main effect of RELATEDNESS over midline channels [$F(2,84) = 3.53$, $p < .05$]. Pair-wise comparisons of the repeated and unrelated conditions [$F(1,42) = 5.51$, $p < .03$] and related and unrelated conditions [$F(1,42) = 6.05$, $p < .02$] substantiated this main effect, while no such effect was observed for the comparison between the repeated and related condition [$F < 1$]. For the 400–700 ms time-window, the statistical analyses showed a main effect of RELATEDNESS for midline electrodes [$F(2,84) = 9.15$, $p < .001$] and lateral electrodes [$F(2,84) = 7.60$, $p < .001$]. Subsequent

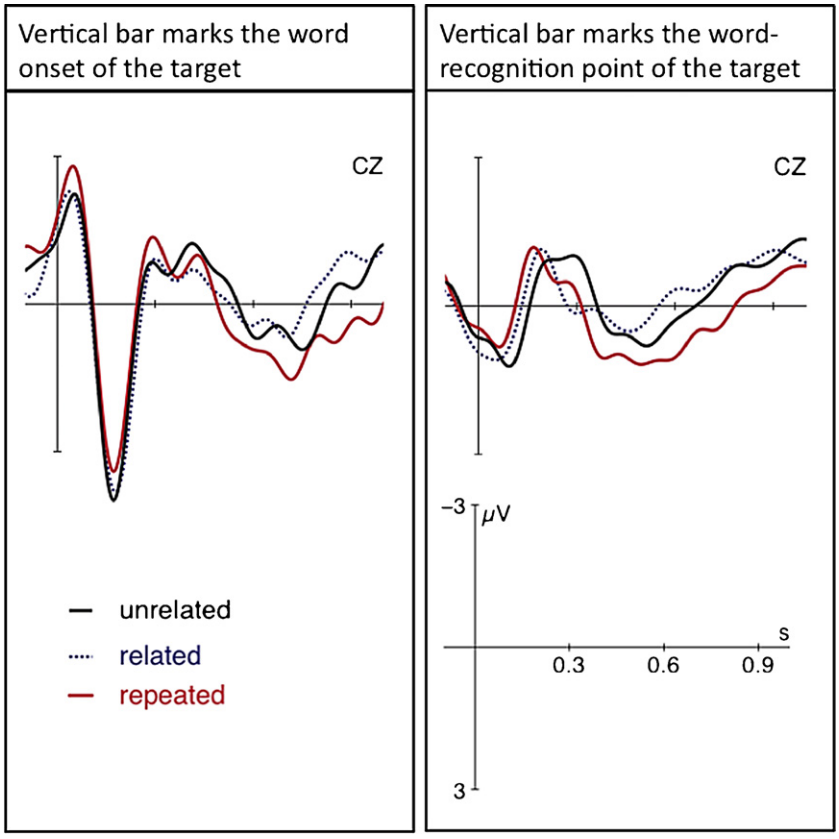

Fig. 2. Grand-average ERPs at selected electrodes for time-locking to the onset of the target (left panel) and time-locking to the recognition point of the target (right panel) for unrelated (black), related (dashed blue) and repeated (red) prime-target combination. (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

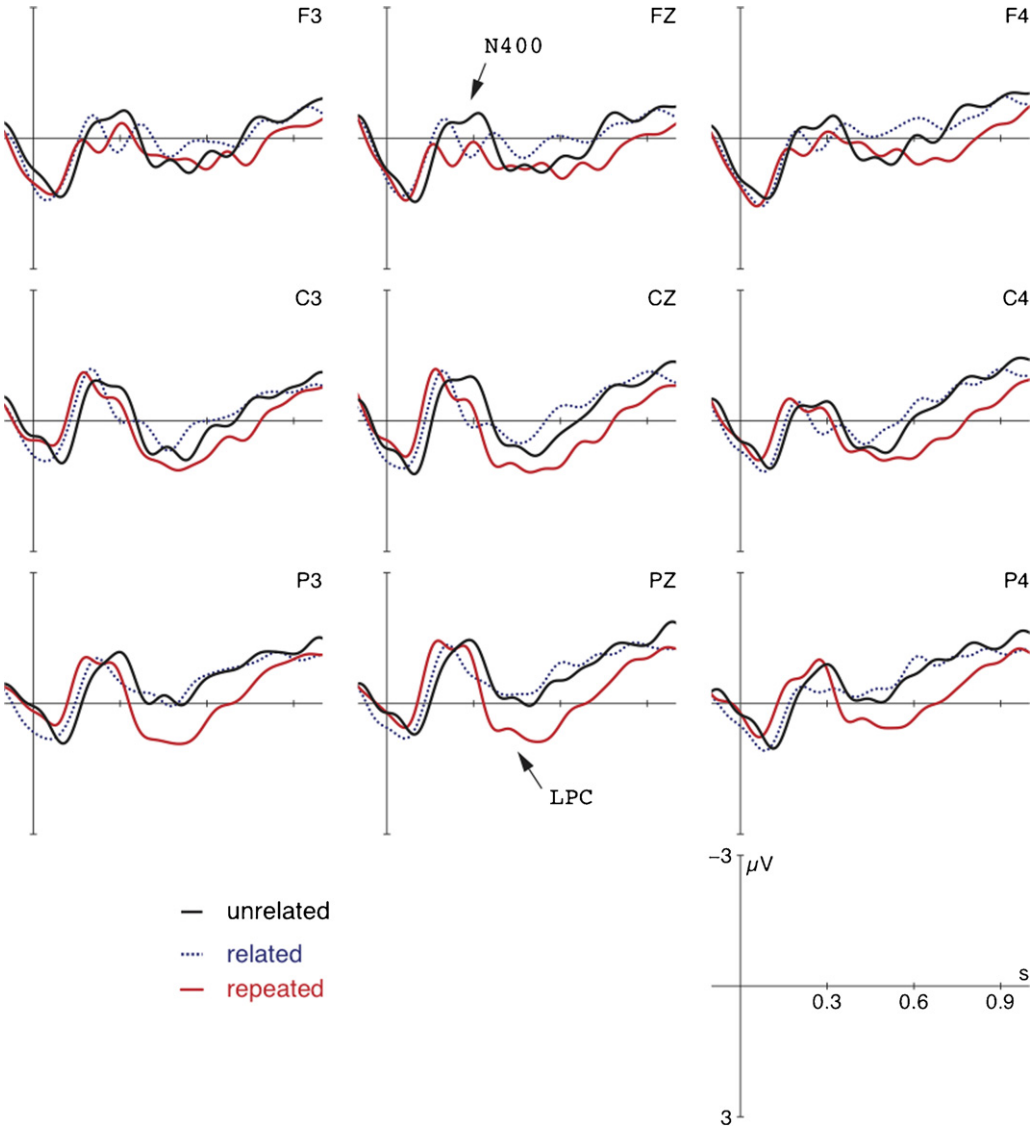

Fig. 3. Grand-average ERPs for 9 selected electrodes for unrelated (black), related (dashed blue) and repeated (red) prime-target pairs. Vertical bar represents the word recognition point of the target. Negativity is plotted up. (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

pair-wise comparisons revealed that there was no reliable difference between the related vs. unrelated condition [all Fs < 3], but significant effects for the repeated vs. related conditions [midline: $F(1,42) = 21.86$, $p < .001$; lateral $F(1,42) = 19.57$, $p < .001$] and for the repeated vs. unrelated conditions [midline: $F(1,42) = 5.64$, $p < .03$; lateral $F(1,42) = 3.60$, $p < .03$].

In the subsequent prime detection task, participants demonstrated a mean recognition rate of 57.6% (17.3 primes in total). This mirrors the chance-level performance typically reported in the masked priming research utilizing various mask effectiveness tests. Furthermore, given that participants were informed about the masking procedure, the overall detection rates in this test might be higher than during the main experiment, when the participants were not informed about the primes and also had to focus on the auditory sentences and the color change task (see also [13] on a similar consideration of overestimation).

4. Discussion

This experiment provides evidence for masked priming effects in sentential context, reflected by differences in the N400 and the late positive component (LPC). The analysis in the N400-window registered a pronounced effect for the unrelated condition in comparison to the repeated and related conditions. This suggests that both repetition and semantic priming facilitate the processing of the target word in sentential context and sheds light on the contribution of discrete lexical information at the compositional level. However, in contrast to previous investigations of associative/semantic priming in word lists [9], there was no reliable difference between the repeated and related conditions. One explanation for this is that the sentential environment has a bearing on the underlying processes and interacts with masked priming effects differentially than in list presentation. If this is the case, a three-way modulation of the N400 should be observable during word list presentation using the same prime-target pairs, which was confirmed by an additional investigation reported in the supplementary data files: when prime and target were presented one after the other in a word list, the ERPs confirmed previous patterns of a three-way distinction with the most pronounced N400-amplitude for unrelated prime-target pairs and an intermediate amplitude for associative priming relative to repetition priming. Since the N400-difference between repetition and semantic priming disappears in sentential

context, our data provide evidence that N400 priming effects are affected differently in list and sentence contexts, where the former shows varying processing demands for repetition and semantic priming, while in sentential context the associative strength of repeated or related primes does not exert N400-modulations. This indicates that repetition and semantic priming are equally facilitated during sentence processing.

Hence, in accord with prior masked priming ERP studies utilizing word lists [6,9,13], masked primes to auditorily presented target words in sentential contexts evoked a priming effect in the N400-window, with unrelated primes producing the most pronounced negativity. These N400-modulations indicate semantic processing differences, which are most enhanced when prime and target do not share relevant lexical-semantic features. Moreover, supporting previous research on context effects and priming in unmasked paradigms [24], the results show that masked priming effects are produced in both word lists and richer contexts. Yet, the data also demonstrate an interesting difference between associative priming effects in word lists and sentential contexts. While previous findings of N400-differences between related and repeated primes in masked priming [9] and attentional blink manipulations [17] were replicated in the list presentation, no such difference was observable in the sentential context, i.e., repeated and associative primes produced equally attenuated N400-amplitudes. This suggests that the target word was similarly easily integrated with the sentential context, when a repeated or related prime occurred. These findings might indicate that lexical-semantic networks are activated more strongly in sentential context, facilitating repeated and semantically related prime-target combinations in a similar manner. The N400-modulations indicate that the associative strength of a prime affects the processing of the target in such a way that repetition and semantic priming equally result in less associative demands during integration. Preceded by an unrelated prime, integration was more difficult, reflected by a more pronounced N400.

There are very few studies reporting LPC effects in connection with masked priming [14]. Findings from recall studies suggest that the amplitude of the LPC is a strong indicator for a target to be recollected, both consciously and incidentally [16,20]. However, since we did not find the LPC in list presentation, we argue that it should be related to the sentential context. As the supplementary data indicate, the sentential context, but not the list presentation, registered an additional positivity (LPC) for repeated words. Since we used the same experimental parameters in the two studies, these differences cannot be attributed to design features, such as timing or stimuli selection, but to the specific demands exerted by cross-modal masked priming in sentential context. Accordingly, it is possible that the sentential context interacts with recall in enhancing it or the influence of the sentential context can be explained by a discourse perspective.

At first view, repetition priming in sentential contexts may enforce recollection. Following this line of argumentation, the data would suggest that participants only experience recollection with a repeated prime, but not with a semantically related prime. Along these lines, the LPC reflects operations independent from lexical-semantic processing and may just reflect word form repetition. In contrast to the claim that the LPC is an indication for a certain extent of conscious awareness of the repetition [14], the absence of a LPC in the supplementary data suggests that timing or masking alone cannot account for this effect. Rather, the current data appear to propose that the linguistic environment of the experiment interacts with repetition priming. We suggest that the data cannot simply be explained along an account that distinguishes between implicit and explicit detection of repetition, but the role of the sentential context must be considered.

An alternative explanation for the occurrence of the LPC might be the redundancy arising from repetition priming. While in natural discourse, repetition is used to establish a coreference relation with a previously mentioned entity and is therefore a vital means in the construction and maintenance of the discourse representation structure, repetition in the masked priming environment results in an unecological reiteration. Previous research has shown that coreferential repetition in discourse does not yield a late positive deflection (while the integration of new expressions does) [1,24]. The positivity observed for the repeated words might therefore represent a response to the superfluous reoccurrence of the target expression. This raises the question why the repetition should have a stronger effect than the possible mismatch triggered by related and unrelated primes, which might also interfere with the construction of the discourse representation structure. One explanation may be that the activation of lexical-semantic networks may not be as disruptive to language comprehension and to the construction of the discourse representation as the clash generated by repeated prime-target pairs is.

5. Conclusions

In the present investigation we set up an experimental paradigm that combines cross-modal masked priming and ERP recordings during sentence processing. We demonstrated that masked repetition and associative/semantic priming effects are observable in electrophysiological responses in different presentation contexts: not only word lists – as already reported in the literature – but also sentential contexts. Critically, the data highlight two context-specific differences targeting the N400 and the LPC respectively. The results of the current investigation further suggest that cross-modal masked priming coupled with the recording of ERPs is a valuable approach to investigate the temporal dynamics of lexical/semantic processing and meaning construction at the sentence and text level.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.neulet.2012.09.057.

References

[1] P. Burkhardt, Inferential bridging relations reveal distinct neural mechanisms: evidence from event-related brain potentials, Brain and Language 98 (2006) 159–168.
[2] J. Grainger, K. Diependaele, E. Spinelli, L. Ferrand, F. Farioli, Masked repetition and phonological priming within and across modalities, Journal of Experimental Psychology Learning, Memory, and Cognition 29 (2003) 1256–1269.
[3] J. Grainger, P.J. Holcomb, Watching the word go by: on the time-course of component processes in visual word recognition, Language and Linguistics Compass 3 (2009) 128–156.
[4] G. Grossi, Relatedness proportion effects on masked associative priming: an ERP study, Psychophysiology 43 (2006) 21–30.
[5] P.J. Holcomb, J.E. Anderson, Cross-modal semantic priming – a time-course analysis using event-related brain potentials, Language & Cognitive Processes 8 (1993) 379–411.

[6] P.J. Holcomb, J. Grainger, On the time course of visual word recognition: an event-related potential investigation using masked repetition priming, Journal of Cognitive Neuroscience 18 (2006) 1631–1643.
[7] P.J. Holcomb, J. Grainger, Exploring the temporal dynamics of visual word recognition in the masked repetition priming paradigm using event-related potentials, Brain Research 1180 (2007) 39–58.
[8] P.J. Holcomb, J. Grainger, ERP effects of short interval masked associative and repetition priming, Journal of Neurolinguistics 22 (2009) 301–312.
[9] P.J. Holcomb, L. Reder, M. Misra, J. Grainger, The effects of prime visibility on ERP measures of masked priming, Cognitive Brain Research 24 (2005) 155–172.
[10] G. Keppel, Design and Analysis: A Researchers Handbook, Prentice Hall, Englewood Cliffs, NJ, 1991.
[11] M. Kiefer, The N400 is modulated by unconsciously perceived masked words: further evidence for an automatic spreading activation account of N400 priming effects, Cognitive Brain Research 13 (2002) 27–39.
[12] M. Kiefer, M. Spitzer, Time course of conscious and unconscious semantic brain activation, Neuroreport 11 (2000) 2401–2407.
[13] K. Kiyonaga, J. Grainger, K. Midgley, P.J. Holcomb, Masked cross-modal repetition priming: an event-related potential investigation, Language & Cognitive Processes 22 (2007) 337–376.
[14] M. Misra, P.J. Holcomb, Event-related potential indices of masked repetition priming, Psychophysiology 40 (2003) 115–130.
[15] T.B. O'Rourke, P.J. Holcomb, Electrophysiological evidence for the efficiency of spoken word processing, Biological Psychology 60 (2002) 121–150.
[16] K.A. Paller, M. Kutas, H.K. McIsaac, Monitoring conscious recollection via the electrical-activity of the brain, Psychological Science 6 (1995) 107–111.
[17] B. Rolke, M. Heil, J. Streb, E. Hennighausen, Missed prime words within the attentional blink evoke an N400 semantic priming effect, Psychophysiology 38 (2001) 165–174.
[18] M.D. Rugg, The effects of semantic priming and word repetition on event-related potentials, Psychophysiology 22 (1985) 642–647.
[19] M.D. Rugg, Dissociation of semantic priming, word and non-word repetition effects by event-related potentials, The Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology 39 (1987) 123–148.
[20] M.D. Rugg, M.E. Nagy, Event-related potentials and recognition memory for words, Electroencephalography and Clinical Neurophysiology 72 (1989) 395–406.
[21] P.B. Schumacher, S. Baumann, Pitch accent type affects the N400 during referential processing, Neuroreport 21 (2010) 618–622.
[22] D.A. Swinney, W. Onifer, P. Prather, M. Hirshkowitz, Semantic facilitation across sensory modalities in the processing of individual words and sentences, Memory and Cognition 7 (1979) 159–165.
[23] C. van Petten, S. Coulson, S. Rubin, E. Plante, M. Parks, Time course of word identification and semantic integration in spoken language, Journal of Experimental Psychology Learning, Memory, and Cognition 25 (1999) 394–417.
[24] C. van Petten, M. Kutas, R. Kluender, M. Mitchiner, H.K. McIsaac, Fractionating the word repetition effect with event-related brain potentials, Journal of Cognitive Neuroscience 3 (1991) 131–150.