# The interdependence of spatial attention and lexical access as revealed by early asymmetries in occipito-parietal ERP activity

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## Abstract

A test of the possible functional interaction between mechanisms subserving spatial attention and lexical access was devised by displaying one green and one red string of letters, one to the left and one to the right of fixation, and having participants attend to a target string defined by color while ignoring the other distractor string. The target string for a delayed lexical decision task could be a word or a nonword. The distractor was always a word. When the target was a word, target and distractor were associatively related on half of the trials and not related in the other trials. The event-related potential time-locked to the onset of the letter strings produced an N2pc (a greater negativity at scalp sites contralateral to the target relative to the ipsilateral sites arising at about 170 ms poststimulus). N2pc amplitude was reduced when the words were related relative to when they were not related. The results provide direct, online evidence that the rapid activation of meaning by visual words can influence the efficiency of the deployment of spatial attention.

**Descriptors:** Spatial attention, Lexical access, N2pc, Semantic processing

Responses to stimuli presented at an attended location are faster, and often more accurate, than responses to stimuli presented at an unattended location (Posner, 1978). Spatial attention can also modulate the amplitude of a number of components of the event-related potentials caused by visual stimuli (e.g., Mangun, 1995). Given the importance of reading for most individuals, we investigated the functional interactions between mechanisms controlling visual spatial attention and those involved in the processing of visually presented words.

There are at least two areas of research that have separately produced results that may help to characterize the functional relationship between word recognition and spatial attention mechanisms in the human brain. One area of study, which has traditionally relied on chronometric techniques in lexical decision and naming tasks, has focused primarily on the issue of whether lexical access can occur for words displayed at unattended spatial locations. A cuing paradigm has been used frequently in this context, whereby a to-be-processed target word is preceded by a spatial cue that can be displayed either in the same position as that occupied later by the target (valid trials) or in a different position (invalid trials). The assumption underlying the use of the cuing paradigm is that the focus of attention is narrowed to the cued location shortly after the onset of the spatial cue, leaving scarce attention resources in locations other than the cued loca-

tion. Work in this area has generated inconclusive results. McCann, Folk, and Johnston (1992), for instance, found that lexical decision time was generally shorter for validly cued words than for invalidly cued words. Furthermore, these authors found additive effects of cue validity and lexical frequency manipulations on lexical decision time and interpreted these results as support for the hypothesis that spatial attention and word recognition are mental processes subserved by functionally independent mechanisms. Spatial attention, in the view of McCann et al., has to be deployed to the target word before processing of the word can begin.

Others have questioned this conclusion and demonstrated active processing of words displayed at unattended spatial locations. Brown, Gore, and Carr (2002) cued one of three possible spatial locations where a to-be-named color patch was subsequently displayed. A color word and/or a neutral word were presented in each of the other two positions (i.e., those not occupied by the color patch). Not surprisingly, when the color word was invalidly cued, the results showed a sizable Stroop effect. Critically, however, a reduced but still significant Stroop effect was observed even when the color patch was validly cued, suggesting that the color word, although held to be outside of the focus of attention, was processed at a lexical level.

Other research in this area has highlighted the crucial role played by the relative proportion of validly versus invalidly cued trials in varying the degree of interaction between word recognition and spatial attention mechanisms (Besner, Risko, & Sklair, 2005). Stolz and McCann (2000) used a priming

paradigm in which a prime word was centrally displayed, followed by a target word that could be displayed above or below a central fixation point. Target onset was preceded by a spatial cue, and the percentage of trials in which the cue validly predicted the position of the target was systematically manipulated. The results showed reliable priming when prime and target were semantically associated words. The amount of priming interacted with cue validity only when the cue predicted the spatial position of the target with high probability (i.e., $p = .8$), but not when the cue was uninformative of the target position (i.e., $p = .5$). The authors concluded that spatial attention, when focused on a word, may interact with word identification mechanisms in a number of ways, likely by modulating the uptake of orthographic information and/or by speeding up the connection between semantic and lexical information once the orthographic processing of the letter string has terminated (see also Stolz & Stevanovski, 2004).

Other studies that have established important constraints on models of spatial attention and word processing have monitored the length of eye fixations during skilled reading. It is undisputed that fixation time is a reliable index of various processing stages during word recognition, insofar as the time spent fixating a word has been shown to be sensitive to a number of lexical variables. Fixation time, for instance, is usually shorter for short words compared to long words, and shorter for high frequency words compared to low frequency words (e.g., Rayner, 1998, for a review). Furthermore, fixation time is shorter for words that occur in semantically congruent contexts compared to words occurring in contexts that are semantically incongruent (Sereno, Brewer, & O'Donnell, 2003).

One crucial observation concerning the relationship between spatial attention and word recognition mechanisms that can be derived from research in this area is related to the absolute duration of an eye fixation. An eye fixation takes 250 ms on average. Considering that about 60 ms are needed for the visual signal to travel from the retina to high level cortical areas where word processing is hypothesized to begin (e.g., Ishida & Ikeda, 1989) and that 150 ms on average are required for the motor programming of the subsequent saccade (Rayner, Slowiaczek, Clifton, & Bertera, 1983), a tenet of extant models of reading developed in this context is that lexical access must be well under way during the first 100–150 ms of the beginning of the fixation (Sereno & Rayner, 2000; Sereno, Rayner, & Posner, 1998). Importantly, this timeline is critical for constraining models of when, during skilled reading, spatial attention starts to interact with mechanisms devoted to the motor programming of the next saccade. Sereno and Rayner (2003) have recently proposed that spatial attention mechanisms initiate their operations either in concomitance with lexical access or shortly after. The parafoveal preview effect, namely, the lengthening of fixation time to a target word that occurs when the target is replaced for a brief interval with a nonword string during the fixation of the word to the left of the target (e.g., Balota, Pollatsek, & Rayner, 1985), is usually taken as support for this view. This preview effect suggests that spatial attention visits words at the right of fixation while the visual system is engaged in acquiring lexical information from the fixated word.

Empirical evidence consistent with the principle of very fast lexical access in word recognition has been collected using techniques based on electroencephalographic (EEG) and magnetoencephalographic (MEG) recordings. Sereno et al. (1998) presented participants with high-frequency or low-frequency regular and irregular English words. Half of their participants performed a reading task on sentences in which the target words were embedded while their eye movements were recorded whereas the other half performed a lexical decision task on the same target words and the event-related potential (ERP) time-locked to the targets was calculated. The manipulation of lexical frequency produced significant effects on both target fixation time and on the shape of the target-locked ERP. Participants fixated high-frequency words for a shorter time (275 ms) relative to low-frequency words (295 ms), that is, the frequency effect amounted to a 20-ms benefit as frequency was increased. Interestingly, the frequency manipulation was reflected in a significant modulation of the ERP that started as early as 132 ms posttarget, that is, in the N1 range. Given the consensus that evidence of frequency effects is a reliable index of lexical access (e.g., Balota, 1990), the authors concluded that the ERP results were consistent with eye fixation estimates to indicate a time for lexical access that was no longer than 200 ms.

The present work proceeds from two considerations. One consideration concerns the time course of semantic processing in relation to the speed of lexical access. Pulvermüller, Assadollahi, and Elbert (2001) recorded the magnetoencephalogram while participants performed lexical decisions on distinct sets of words that varied in strength of semantic association. Function words scored low in semantic association whereas words that were names of real-world objects thought to elicit promptly the idea of an action scored high in semantic association. The degree of semantic association was considered to be the only variable distinguishing the word sets, because other lexical variables (e.g., orthographic complexity and similarity, lexical frequency, and number of letters/syllables) were carefully matched across the distinct word sets. Differences in the event-related magnetic fields across the different sets of words were apparent as early as 150 ms following word onset, with the magnetic field responses being particularly pronounced for words characterized by strong semantic association. These findings supported two important conclusions. First, semantic access was extremely fast, consistent with Sereno and Rayner's (2000, 2003) earlier suggestions. Secondly, the speed of semantic access was comparable in that study with the speed of lexical access found in prior studies on eye movements in skilled reading, suggesting that lexical access and semantic access are temporally coincident and functionally interdependent mental processes (for similar conclusions, see also Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006; Pulvermüller, 2001). To note, evidence of a differential event-related magnetic response in Pulvermüller's studies was particularly pronounced when calculated based on signals recorded over the left infero-temporal regions of the head (see also Pulvermüller, Shtyrov, & Ilmoniemi, 2005).

The second consideration is that, whereas evidence suggesting a rapid access of lexical/semantic information from words (and also from pictures; see Thorpe, Fize, & Marlot, 1996) is present in the literature, as described above, specific electrophysiological evidence of the interaction between lexical/semantic access mechanisms and mechanisms responsible for the allocation of spatial attention is still lacking. Electrophysiological studies of visual attention show that the locus of visual spatial attention can be tracked by measuring the N2pc ERP component as participants process a visual display for the presence of a target stimulus (in the absence of eye movements). The N2pc (N2 posterior contralateral) is a lateralized ERP characterized by a greater negativity at posterior sites contralateral to the visual hemifield occupied by a to-be-processed target when displayed surrounded

by distractors, as is typical in visual search paradigms (Luck & Hillyard, 1994). As the term suggests, the N2pc component has a posterior scalp distribution, and it is estimated by computing the difference between the contralateral voltage and the ipsilateral voltage at corresponding electrode sites (e.g., P7/P8) positioned symmetrically about the midline. The onset of the N2pc is usually at about 170–180 ms poststimulus, with a peak often between 220 and 250 ms and with potential latency variations owing to the difficulty in target localization (e.g., Wascher, 2005; Woodman & Luck, 2003). This component seems to arise primarily from lateral portions of the extrastriate and infero-temporal visual areas, with a possible contribution of posterior parietal areas (e.g., Hopf et al., 2000). Luck and his colleagues have provided evidence linking the N2pc to mechanisms of visual spatial attention. Several results led them to emphasize the potential role of distractor suppression in the generation of the N2pc (e.g., Luck & Hillyard, 1994). Others have, however, argued that the N2pc may reflect processes of target enhancement rather than distractor suppression (e.g., Eimer, 1996).

Based on the above considerations, the logic of the present investigation was the following. If lexical/semantic access occurs in the first 150 ms of a word onset, lexical access and the mechanisms devoted to the control of spatial attention—whose reflections are evident in N2pc modulations, starting 180 ms poststimulus—could interact, because these two sets of processing mechanisms overlap temporally to a substantial extent. Such interaction would dovetail nicely with findings obtained using the visual world paradigm (e.g., Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). In this paradigm, participants are exposed to visual arrays including multiple line drawings of real-world concepts. A word (usually embedded in a sentence) is presented auditorily to the participants, who are invited to look at the visual array with no specific instructions about what exactly in the visual display they should look at. If the visual array contains an object that is the referent of the target word, that specific object is foveated almost immediately, within 100–150 ms from the onset of the spoken word. Huettig and Altmann (2005) speculated that this oculomotor reaction must be driven by the rapid allocation of attention to the referent object as soon as enough lexical information is collected from the spoken word. Crucially, these authors have also shown that these fast fixations are semantically modulated, given that an object related conceptually to the spoken target is fixated more rapidly (and frequently) compared to a distractor object in the visual array that is not semantically related with the spoken target.

The logic described above was implemented in an experimental paradigm designed to monitor an N2pc response in a lexical decision task to lateralized pairs of words that varied in associative strength. We displayed one green and one red string of letters, one to the left and one to the right of fixation, and instructed participants to attend to just one of them (e.g., the red one). The distractor (e.g., green) string was always a word. A delayed (unspeeded) lexical decision to the target string was required at the end of each trial. When the target was a word, target and distractor were associatively related on half of the trials (e.g., mouse–cheese), and unrelated in the other trials (e.g., mouse–glass). We reasoned that the ERP time-locked to the onset of the letter strings should produce an N2pc contralateral to the target string, because attention would be directed to the target string in order to determine whether it was a word or a nonword. Much simpler shape judgment tasks in similar bilateral displays produced large N2pc responses (e.g., Brisson & Jolicœur, in

press; Dell'Acqua, Sessa, Jolicœur, & Robitaille, 2006; Eimer, 1996; Eimer & Mazza, 2005; Jolicœur, Sessa, Dell'Acqua, & Robitaille, 2006a, 2006b). The critical question was whether the strength of the associative relation between the target and the distractor would exert a modulatory influence on the N2pc in these circumstances. Evidence for such an interaction would show that rapid semantic activation can influence the deployment of visuo-spatial attention in the absence of eye movements.

Several predictions are possible as to how the N2pc would reflect access to semantic information from the distractor word. If semantically related distractors delayed the allocation of attention to the target word, this should be reflected by a latency variation of the N2pc, with longer N2pc latencies on trials where target–distractor pairs are semantically associated. Alternatively, it is possible that attention would be initially allocated to the distractor on a proportion of trials, and that this happens more frequently on trials where distractors are semantically related to target words. This should be reflected by an overall reduction of N2pc amplitude in trials with semantically related distractors relative to trials with semantically unrelated distractors. In either case, any systematic effect of the associative relation between target and distractor on N2pc amplitude and/or latency would provide unequivocal evidence that rapid semantic activation from words can affect the allocation of visual attention.

## Method

### Participants

Nineteen university students (11 women), with an age ranging from 18 to 35 years (mean = 25), participated in the experiment for course credit. All had normal or corrected-to-normal vision, and none reported a history of prior neurological disorder.

### Apparatus and Stimuli

The criteria for the selection of the word stimuli were analogous to those used in a prior study in which semantic associative effects were systematically investigated using a rapid serial visual presentation paradigm (Potter et al., 2005). This was done with the explicit intention to maximize the probability of observing a semantic effect in the present lexical decision task. One hundred twenty Italian four-letter and five-letter uppercase words were selected from the VELI corpus (1989) as target words. Each of them was paired with an associatively related distractor word (e.g., Italian *cane–osso*; English *dog–bone*) and with an associatively unrelated distractor word (e.g., Italian *cane–seta*; English *dog–silk*) of the same length as the target. Related distractors and unrelated distractors were matched for frequency (mean log-transformed values of frequency of occurrence over 1 million = 2.75 and 2.87 for related and unrelated distractors, respectively; $t[119] = 1.51$, $p > .13$) and orthographic similarity (mean number of letters shared between a given target/distractor pair = 0.76 and 0.71 for related and unrelated distractors, respectively, $t[119] = 1.62$, $p > .11$) with the target. The same distractors were also paired with pronounceable nonwords generated by changing one letter to 120 words that shared no associative relation with the distractors or the targets. The letter strings displayed on a given trial were always of the same length, which varied between 2.3° and 2.5° at a viewing distance of approximately 80 cm. The distance from the center of a letter string to the center of the screen was 2.8°. The stimuli were displayed

one in red and one in green on the black background of the screen, preceded and followed by gray masks consisting of pairs of hash mark strings of the same length as the string of letters. Gray, red, and green colors were equiluminant (44 cd/m$^2$) on a black background (6 cd/m$^2$).

### Design and Procedure

Each trial began with a centrally presented fixation cross. Participants initiated the trial by pressing the spacebar on the computer keyboard. A blank interval of 500 ms elapsed prior to the presentation of two lateral premasks that lasted 85 ms. The premasks were immediately replaced by the two letter strings that were exposed for 85 ms. A blank screen was then exposed for 51 ms, followed by the presentation of two postmasks (pre- and postmasks were identical) for 85 ms. The blank screen served the purpose of minimizing the occurrence of integration between the target and the postmask, which might have allowed subjects to recover the information relevant for the lexical decision task based on the word stimuli persistence (e.g., Bachmann & Allik, 1976; Giesbrecht & Di Lollo, 1998), and reach an uninformative ceiling level of behavioral performance. After the offset of the postmasks, 1000 ms elapsed before a question mark was displayed at the center of the screen that prompted participants to enter a response. Participants were instructed to pay attention to the letter string of a given color, with half of the participants attending to the red string and the other half to the green string, while ignoring the string of different color. With no speed pressure, participants pressed the "1" key of the numeric keypad to respond "word" or the "2" key to respond "nonword." The responses had to be entered using the right hand.[1] Each participant performed one block of 15 practice trials, followed by four blocks of 120 experimental trials. In each block, the side of target presentation, the associative relation, and the lexicality of the target were fully crossed. The particular words used in the various conditions were counterbalanced across participants such that each word occurred equally often in each condition.

### EEG/ERP

Using a head cap with tin electrodes, EEG activity was recorded continuously from the Fp1, Fp2, Fz, F3, F4, F7, F8, C3, C4, Cz, P3, P4, Pz, O1, O2, T7, T8, P7, and P8 sites (see Pivik et al., 1993), referenced to the left earlobe. HEOG activity was recorded bipolarly from electrodes positioned on the outer canthi of both eyes. VEOG activity was recorded bipolarly from two electrodes, above and below the left eye. EEG, HEOG, and VEOG activities were amplified, filtered using a bandpass of 0.01–80.0 Hz, and digitized at a sampling rate of 250 Hz. Impedance at each electrode was maintained below 5 kΩ. The EEG was re-referenced off-line to the average of the left and right earlobes, and segmented into 1200-ms epochs starting from 200 ms prior to the onset of the letter strings. Trials associated with a HEOG exceeding ± 30 μV were discarded from analysis. Trials with artifacts due to eye movements, excessive muscle activity, or amplifier saturation were eliminated (8.0%). Signal-averaged

HEOG was used as control for possible eye movements. The difference between left and right HEOG electrodes was averaged separately for trials in which the target was displayed to the right and to the left of the central fixation point. A maximum deflection of less than 3 μV was observed in each participant, ensuring that the average eye position did not deviate by more than 0.2° toward the target during the ERP epoch. The N2pc amplitude was calculated based on activity recorded at O1/O2, P7/P8, P3/P4, in a 180–300-ms time window. For each electrode pair, the ERP contralateral to the target word was calculated by averaging the ERP generated at the left-sided electrode when the target was displayed in the right visual hemifield and the ERP generated at the right-sided electrode when the target was displayed in the left visual hemifield. The ERP ipsilateral to the target was calculated with an analogous algorithm, by averaging the ERPs at the complementary sites. The N400 amplitude was calculated based on activity recorded at Cz and Pz, in a 350–550-ms time window. The data from 2 participants were discarded from all analyses because of excessive eye movements.

### Results

Only the trials of interest for the present purposes, that is, those in which target and distractor were both words, were included in the following analyses. Behavioral performance data (the mean proportion of correct responses in the unspeeded lexical decision task) were submitted to an analysis of variance (ANOVA) that considered word associative relatedness and the visual hemifield occupied by the target word (left vs. right) as within-subjects factors. These mean proportions are reported in Table 1. The ANOVA indicated that lexical decision accuracy was significantly higher when target and distractor words were related relative to when they were unrelated, $F(1,16) = 8.2$, $p < .02$; that is, a facilitatory associative priming effect was observed in the accuracy results. Furthermore, lexical decision accuracy was significantly higher when the target words were displayed in the right visual hemifield than in the left visual hemifield, $F(1,16) = 6.8$, $p < .02$. The interaction between these factors was not significant ($F < 1$).

A summary of the most important electrophysiological results is shown in Figure 1, where the ERPs time-locked to word pairs onset are reproduced as a function of the factors manipulated in the present design. The mean amplitudes of the contra- minus ipsilateral ERPs, in a 180–300-ms time window, were submitted to an omnibus ANOVA with electrode site (O1/O2, P7/P8, P3/P4) and word relatedness as within-subjects factors. A Greenhouse–Geisser correction was used when appropriate.[2]

As can be seen in Figure 1B, the N2pc had a lower amplitude in the related condition compared with that in the unrelated condition, $F(1,16) = 7.7$, $p < .02$. There was also a significant main effect of electrode site, $F(2,32) = 8.1$, $p < .003$. The interaction between these two factors was not significant, $F(2,32) = 1.1$, $p > .3$. Paired contrasts indicated that the N2pc had a high amplitude at P7/P8, an intermediate amplitude at O1/O2, and a small amplitude at P3/P4 (P7/P8 vs. O1/O2: $F[1,16] = 3.2$, $p < .08$; P7/P8 vs. P3/P4: $F[1,16] = 15.8$, $p < .002$; P3/P4 vs. O1/O2: $F[1,16] = 8.2$, $p < .02$). When the data from the different electrode sites were pooled, separate $t$ tests against the

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[1]The verbatim instructions to the participants were as follows: "On each trial of the present experiment, you will see two strings of letters, one red and one green, displayed on opposite sides of vertical meridian bisecting the screen. The words will be displayed quickly, preceded and followed by masking stimuli. While doing your best to not move your eyes throughout the experiment, you have to respond only to the RED (GREEN) string by pressing '1' or '2' on the numeric keypad depending on whether the string was a word or a nonword, respectively."

[2]The pre-onset deflections evident in the unsubtracted ERPs (Figure 1A, C) were likely due to word pairs including the target being preceded by the abrupt onset of bilaterally displayed pattern masks.

**Table 1.** *Mean Proportion of Correct Lexical Decision Responses for Target Words in the Left or Right Visual Hemifield, in the Related and Unrelated Conditions*

|                  | Target visual hemifield | |
| ---------------- | ----- | ----- |
| Word relatedness | Left  | Right |
| Related          | .71   | .82   |
| Unrelated        | .66   | .79   |

null mean indicated that the N2pc component was present at each level of the word relatedness factor, $t(16) = 2.8$, $p < .02$ for the related condition; $t(16) = 4.3$, $p < .01$ for the unrelated condition.

An ANOVA considering the same factors was carried out on the N2pc peak latency, which was extracted from the contra-minus ipsilateral ERPs as the point in time at which the largest negative value was detected in a 180–300-ms time window. This
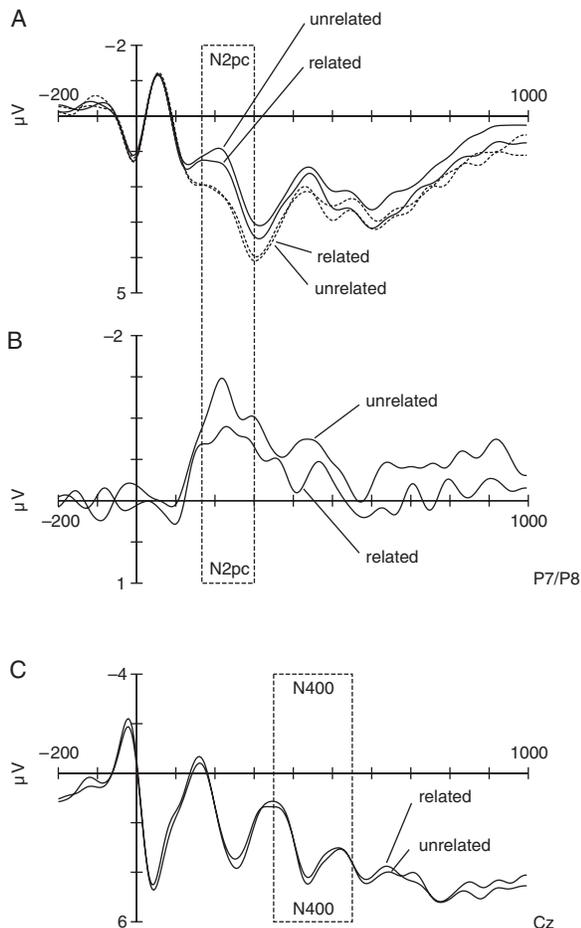


**Figure 1.** Electrophysiological results based on the analysis of trials in which target and distractor were both words. Upper panel, A: Unsubtracted ERP waveforms contralateral (solid lines) and ipsilateral (dashed lines) to the target word, as a function of associative relation. Upper panel, B: Contra- minus ipsilateral ERP waveforms, as a function of associative relation. The box labeled N2pc provides an indication of the time window considered in the N2pc analyses. Lower panel, C: Standard ERP waveform as a function of associative relation. The box labeled N400 provides an indication of the time window considered in the N400 analysis.
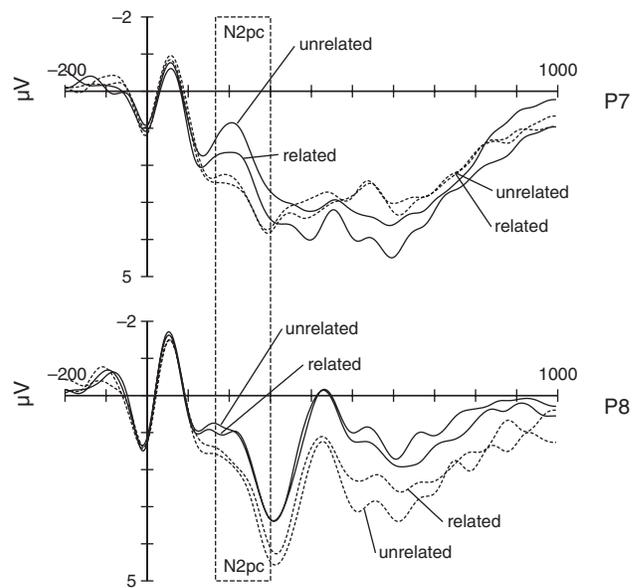


**Figure 2.** Electrophysiological results based on the analysis of trials in which target and distractor were both words. Upper panel, P7: Unsubtracted ERP waveforms contralateral (solid lines) and ipsilateral (dashed lines) to the target word recorded at P7, as a function of associative relation. Lower panel, P8: Unsubtracted ERP waveforms contralateral (solid lines) and ipsilateral (dashed lines) to the target word recorded at P8, as a function of associative relation. The box labeled N2pc provides an indication of the time window considered in the N2pc analyses.

analysis did not reveal any significant effects of electrode site, $F(2,32) = 0.92$, $p > .7$, word relatedness, $F(1,16) = 2.4$, $p > .14$, and of the interaction between these two factors, $F(2,32) = 1.3$, $p > .26$.

An additional ANOVA was carried out on the unsubtracted mean ERP amplitude in the N400 time range, considering word relatedness and recording site (Pz vs. Cz) as within-subjects factors. As expected based on visual inspection of the waveforms shown in Figure 1C, this analysis found no significant results ($Fs < 1$).

A statistical test for the possible interhemispheric asymmetry of word relatedness effects on the N2pc amplitude was devised by isolating the data recorded from P7/P8 (i.e., where N2pc activity was maximal) and submitting them to a further ANOVA in which hemispheric laterality (P7 vs. P8) and word relatedness were considered within-subjects factors. The ERP waveforms are shown in Figure 2.

The ANOVA revealed a significant effect of word relatedness, $F(1,16) = 5.5$, $p < .03$, and a significant interaction between this factor and laterality, $F(1,16) = 7.4$, $p < .05$. As Figure 2 shows, there was a clear tendency of the N2pc modulation by word relatedness to be more pronounced at P7 than at P8. Indeed, when the data recorded at P8 were separately considered, the word relatedness effect did not reach statistical significance, $F(1,16) = 3.1$, $p > .09$.

## Discussion

The central finding of the present study was that the amplitude of the N2pc component elicited by a lateralized target word identified by color was systematically affected by the associative

relationship between the target word and a distractor word displayed in the opposite visual hemifield. The amplitude of the N2pc was attenuated when target and distractor words were related compared to when the words were unrelated, and this difference between the related and unrelated conditions emerged starting at 170–180 ms after the presentation of the word pair (Figures 1A,B, 2). Because this early ERP effect could only arise on the basis of the differential associative relationships between target and distractor words, the present results provide strong evidence that each of the two words must have activated meaning representations prior to, or while, spatial attention was allocated to the target word, at least on a significant proportion of trials. Consequently, the present results provide direct, online evidence for the interaction between mechanisms mediating lexical/semantic access and mechanisms mediating the allocation of attention resources in the visual space. Two remarks are in order at this level. First, this conclusion does not hinge on any particular model of the N2pc, as it is entirely based on the observation that the electrophysiological responses diverged prior to 200 ms as a result of an experimental manipulation in which the only systematic difference between conditions was that concerning associative relatedness. Hence, this difference could only arise after the two words activated their respective meaning. Furthermore, the semantic effect found on the N2pc was entirely reflected in a modification of the amplitude, and not the latency, of this component. As we have argued in the Introduction, one possibility to account for this fact is to assume that attention was attracted by the distractor word on a subset of trials, and that this was more likely to occur on trials where target and distractor words were semantically related than on trials where they were not related. This would have resulted in an attenuation of the N2pc in the related condition. Alternatively, this attenuation could also have resulted if attention was generally more strongly biased toward the target on unrelated relative to related trials.

In either case, the observation that the N2pc was differentially modulated on related versus unrelated trials demonstrates that the relative balance of visual spatial attention was affected by the associative link between target and distractor words. This is important for the current debate about the interplay between spatial attention and semantic processing (see Stolz & Stevanovski, 2004), because it implies that semantic information can systematically modulate the distribution of attention in the visual field. Given that the N2pc is assumed to be generated in extrastriate visual cortex (Hopf et al., 2000), a viable interpretation of the present findings is that the results of a rapid initial semantic analysis, which might occur in the surroundings of the fusiform gyrus (Wheatley, Weisberg, Beauchamp, & Martin, 2005), are fed either back via reentrant pathways to posterior visual areas or forward to ventral-occipital and inferior temporal areas (or both), where they can bias the allocation of visual spatial attention. Future research will be required to tease apart whether such semantic effects are bound to conditions in which word stimuli fall in the same receptive field of neurons in one or more of these areas or whether instead equivalent effects can be observed when each word is displayed farther out in the visual periphery. Given that 2.8° separated the stimuli used in the present context, and given the property of neurons in these higher order visual areas to have receptive fields crossing over the vertical meridian, this possibility cannot be excluded on the basis of the present results.

Electrophysiologically, word relatedness effects were particularly evident in the data collected at P7, but strongly attenuated at P8—though still in a direction congruent to the semantic effect

detected at P7 (see Figure 2). This result was obtained also by Eimer (1996, Experiment 4) in analogous experimental conditions using words with a spatial referent (i.e., "right" and "left") as to-be-processed stimuli. The presence of a left-lateralized modulation of the semantic effect documented in the present context, and, in particular, in the specific time range examined herein (i.e., 180–300 ms), calls for a certain degree of caution when interpreting the present findings. Certainly, the simplest and probably most natural explanation of the present findings would be that the neural substrate implementing the control of visuo-spatial attention, whose activity is reflected in the N2pc component, is directly interconnected with regions in the inferotemporal cortex held to be responsible for the semantic analysis of lexical stimuli. In this light, what can be observed in the graphs of Figure 1 and Figure 2 could be taken as a functional index of the efficiency with which attention was allocated to the target word depending on the strength of its semantic relation with the distractor word. More importantly, the asymmetry of semantic effects on the N2pc component in this framework would have no other explanation than that related to the known neurophysiology of language processing in the brain and with recent MEG findings documenting the enhanced reactivity to the presentation of verbal material by the left as opposed to right infero-temporal cortex (Pulvermüller, 2001). The trend toward a left-lateralized evidence of semantic modulation might be linked to similarly left-lateralized hemodynamic activation during visual word tasks. Several functional neuroimaging studies have so far reported reading-related left-biased activation in many areas of the extrastriate visual cortex (Petersen, Fox, Posner, Mintun, & Raichle, 1988; Tagamets, Novick, Chalmers, & Friedman, 2000).

One caveat to the present explanation may arise from evidence concerning a specific ERP component, labeled recognition potential (RP; e.g., Martin-Loeches, Hinojosa, Gomez-Jarabo, & Rubia, 1999; Rudell & Hua, 1997), that is usually manifest as occipito-parietal negative activity peaking in a time window of 200–250 ms following the presentation of words at fixation. The RP to word stimuli is particularly pronounced over left posterior occipito-parietal regions (e.g., at P7), probably originating from the left portion of basal extrastriate cortex labeled visual word form area (VWFA; Cohen et al., 2000). Thus, the ERP effects observed in the present study could result from the linear summation of an N2pc component and RP component, which overlap in time. This possibility appears to be remote, however, in light of the known functional properties of the RP. Similar to the MEG activity reported by Pulvermüller et al. (2001), the RP tends to be larger as the semantic strength of word stimuli is increased (e.g., Hinojosa, Martin-Loeches, Munoz, Casado, & Pozo, 2004; Martin-Loeches, Hinojosa, Gomez-Jarabo, & Rubia, 2001), with the degree of semantic association (or semantic redundancy) of specific word stimuli positively correlated with the negativity in the RP time range. This appears incompatible with the present results, given that an increase in semantic association/redundancy (generated by displaying words semantically related) was associated with a decrease in negativity, reflected in an attenuated N2pc response in the related condition compared with that in the unrelated condition.

At first sight, the present results seem inconsistent with some of the conclusions drawn from studies in which cue validity and word relatedness were manipulated orthogonally. Besner et al. (2005), for instance, have shown that when the task was to name a cued target word, priming from an uncued distractor word is observed only when cue validity was 50%. When cue validity was

100%, the priming effect from the uncued distractor disappeared. The conclusions of Besner et al. were that focused spatial attention was a necessary precondition for early processing in reading and, therefore, for lexical access. The present results are apparently at odds with this conclusion if one considers that color, the physical cue used in the present experimental context to bias the participants' attention to one or the other visual hemifield, indicated the target word position with 100% validity. Nonetheless, the uncued distractor (i.e., the ipsilateral distractor word displayed in the different color) had a substantial impact on the target word processing. It is clear that further research will be needed to clarify this specific discrepancy, even though it may be useful to point out that Besner et al.'s design and the present design, though conceptually similar in many respects, are distinct in one important detail. The visual cues used by Besner and colleagues were spatially separated from the to-be-processed stimuli (i.e., the cues were two horizontally arrayed dashes bounding the area where the target word later appeared), and cues preceded the to-be-named word. The present case was substantially different, with the cue and the target word overlapping spatially and, maybe critically, with their onsets being temporally coincident. The present cue–target synchrony (vis-à-vis the asynchrony in Besner et al.'s study) makes it feasible to imagine that spatial attention was still distributed over both the lateral spatial positions at the onset of the word pair (especially because of the abrupt onset elicited by the bilateral forward masking stimuli), whereas attention was likely to be effectively in focused mode when the to-be-named word appeared in Besner et al.'s study.

In contrast to the semantic modulation of the N2pc component, we found no differential N400 response for unrelated word pairs compared with related word pairs (Figure 1C). Although the presence of an N400 is often taken as a reliable indicator that stimuli are processed to the level of semantic access (e.g., Heil, Rolke, & Pecchinenda, 2004; Rolke, Heil, Streb, & Hennighausen, 2001; Vogel, Luck, & Shapiro, 1998), the absence of a differential N400 response in the present study cannot be taken as an indication of the absence of semantic processing, given that we observed differential ERPs, prior to 200 ms, that could only arise as a result of semantic access. The absence of N400 modulation in the present results is however consistent with proposals pointing to N400 activity as an index of semantic integration, rather than access per se (Holcomb, 1993). To corroborate this view, N400 activity modulations are normally found when the eliciting stimulus is semantically evaluated following the prior activation of a context, either via the presentation of a prime stimulus (e.g., Holcomb & Grainger, 2006) or via the inclusion of the word stimulus in a sentence, as done originally in seminal work on the N400 (e.g., Kutas & Hillyard, 1980). In our view, conceptual integration was unlikely to be required in the present paradigm, given the concurrent onset of the word pairs and the fact that no meaningful stimulus capable of establishing a conceptual context preceded the target word. N400 effects are however also notoriously dependent on the type of verbal material used. In priming paradigms, for instance, long-lasting N400 priming effects that can be observed at or after 350 ms poststimulus are most often detected when the degree of lexical association between word pairs is particularly pronounced (e.g., Koivisto & Revonsuo, 2001), which may not have been consistently the case for the verbal material used in the present context. It is therefore important to extend the present research in order to investigate whether there are conditions where semantic effects on N2pc propagate to later activity, such as that reflected in the N400.

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