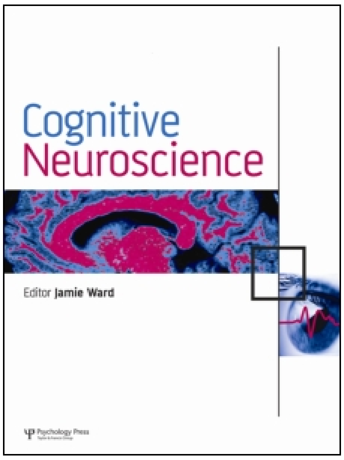

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On the functional nature of the N400: Contrasting effects related to visual word recognition and contextual semantic integration

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On the functional nature of the N400: Contrasting effects related to visual word recognition and contextual semantic integration

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Electrical scalp recordings revealed the brain's sensitivity to both lexical properties of words and their contextual fit with a previous sentence context around 400 ms after word presentation. The so-called N400 component has been suggested to reflect the cost either of target word recognition or of a postlexical process for integrating word meaning into a context. In a sentence comprehension study, we manipulated the potential interference exerted in visual word recognition by target words' orthographic neighbors and the semantic constraints induced by the context in one and the same experiment. Neighbor frequency modulated the N400 only in low-constraint contexts; in high-constraint contexts the largely suppressed N400 did not show this neighbor interference effect. Furthermore, the earlier onset of the ERP effect (about 100 ms) induced by the contextual manipulation compared to the neighbor manipulation suggests distinct neurocognitive processes affecting the N400 component in an interactive manner.

Keywords: ERPs; N400; cloze-probability; Neighbor frequency.

INTRODUCTION

Reading a word usually requires both the recognition of a string of letters as a standardized pattern stored in memory and the integration of its meaning into a context, for example a sentence. These two processes have classically been considered as functionally different, distinguishing between lexical (word

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recognition) and postlexical (integration in a contextual frame) processes (Forster, 1981; Norris, 1994). However, considering the electrophysiological correlates of language processing, these two processes seem to be pursued by our brain in a similar time window: Both lexical manipulations and context-sensitive processing affect the N400 component, i.e., a negative deflection developing around 250 ms, peaking around 400 ms and largest on the posterior areas of the scalp (for reviews see Federmeier, 2007; Kutas, Van Petten, & Kluender, 2006; Lau, Poeppel, & Phillips, 2008). But what this component exactly represents is still a matter of debate.

N400 modulations have classically been reported in sentence comprehension studies manipulating the semantic fit between a critical word and the preceding context. This component's amplitude is negatively related to the ease of integration of a word into a semantic context (Kutas & Hillyard, 1984): The higher cloze-probability ratings[1] are, the lower is the amplitude of the N400. These findings lead to interpret the N400 as reflecting postlexical *integrative* processing (Brown & Hagoort, 1993; Holcomb, 1993): After initial word recognition the context exerts its influence and the N400 would represent the amount of resources necessary for integrating the meaning of a word in an ongoing sentence or a discourse-level representation.

On the other hand, visual word recognition studies using isolated word stimuli suggest that the N400 component reflects the cost in recognizing a standardized string of letters stored in memory: The more difficult the lexical recognition process, the larger is the N400 (for a review see Barber & Kutas, 2007). Visual word recognition (when isolated words are presented) is known to be influenced by target words' orthographic neighbors, i.e., words that orthographically overlap with the target except for one letter (see Andrews, 1997): In Grainger and Jacobs' (1996) model of visual word recognition, upon presentation of a target word, a cohort of neighbor representations would be activated via bottom-up activation from letter to word units. These neighbor representations should be inhibited before full target identification can occur. Accordingly, words empirically take longer to be recognized when they can be confounded with orthographically similar words, especially with such of higher frequency of occurrence (Carreiras, Perea, & Grainger, 1997). Debruille (1998) showed that words having orthographic neighbors of higher frequency elicited larger N400 compared to words having only neighbors of lower frequency. These results support the *lexical* hypothesis, because no integration of the target word—being presented in isolation—in a sentence context was required and such N400 effects could not be considered manifestations of postlexical processes.

To reconcile these findings, an integrative account based on a bottom-up approach would postulate at least two separate neurocognitive sources for the N400 effect (as reported by Halgren, Dhond, Christensen, Van Petten, Marinkovic, Lewine et al., 2002, and Lau et al., 2008): a *lexical* one, modulating the N400 during the recognition of isolated words, and a *postlexical* one, evident in sentence comprehension.

In the present study we contrasted ERP effects due to lexical competition (neighborhood frequency) and to contextual predictability (cloze-probability) in one and the same sentence comprehension experiment. We selected a set of Spanish words with either many (at least one) higher frequency orthographic neighbors or none (similarly to Debruille, 1998). In line with previous findings, the neighborhood frequency manipulation might elicit larger N400s when the target word has possibly strongly interfering neighbors compared to when it has no higher frequency neighbors. These items were presented either in a high (high-cloze context) or in a low constraint (low-cloze context) sentence context. As shown by Kutas and Hillyard (1984), the cloze-probability manipulation should elicit a larger N400 for the low compared to the high-cloze condition.

Differential hypotheses could be put forward regarding the type of processing the N400 should represent. Following the integrative view—the N400 being elicited by (at least) two independent neurocognitive processes—crossing a lexical with a contextual manipulation should elicit *additive* ERP effects on this component.[2] According to bottom-up models of language comprehension, the two present manipulations tap into different processing stages. Therefore, we might find a main effect of cloze-probability for the N400, possibly preceded by another main effect of neighborhood frequency—representing a purely orthographic and not semantic or contextual manipulation—but *no* interaction between the two effects.

On the other hand, *interactive* effects would suggest that one neurocognitive process is influencing both lexical and contextual effects as normally understood to

[1] The cloze-probability is the proportion of people that continue a sentence fragment with a target word.

[2] Following Helmholtz's rule of superimposition, independent electric fields propagating through a conductive medium summate when they intersect. Evidence of additivity in such situations strongly implies independence of the underlying neural sources.

underlie the N400. The lexical account assumes the N400 to reflect the amount of processing needed to recognize the target word: In analogy to interactive activation accounts (Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981), preactivation induced by the context should facilitate lexical processing of the target word. Therefore, a main effect of cloze-probability on the N400 component would be expected accompanied by an interaction with the neighborhood frequency effect due to lexical interference. Interference during the process of visual word recognition coming from higher frequency orthographic neighbors is assumed to become less important with increasing facilitation of the target via top-down processing induced by the context. Furthermore, the high temporal resolution of ERPs might provide evidence for different onsets for the two effects, suggesting a certain degree of independence between lexical and contextual manipulations.

Interactive effects on the N400 have already been reported by both Van Petten and Kutas (1990) and Dambacher, Kliegl, Hofmann, & Jacobs (2006). Word frequency affected the N400 amplitude, being more negative for low- than for high-frequency words. Importantly, this effect disappeared as the contextual constraint increased the expectation for the target word. However, frequent words tend to appear in more contexts than infrequent words, and it can be argued that they are, therefore, generally easier to integrate compared to words that are rarely used in natural language. A general correlation between word frequency and semantic properties can, thus, not be excluded. In addition, frequent words represent frequent perceptual patterns to be processed by the visual system, and we cannot exclude very early perceptual facilitation of the recognition process for frequent words. In the present study, only the frequency of items that are *not* perceived by participants is manipulated and possible neighborhood frequency effects on the N400 could not be interpreted as resulting from a perceptual advantage. Furthermore, manipulating neighborhood frequency controlling for frequency of use should exclude that effects are being driven by semantic properties of target words.

METHOD

Participants

Twenty-six students of the University of La Laguna took part in the experiment for course credits. Two of them were not considered in the analyses due to an excessive number of muscular artifacts. The remaining 24 subjects (mean age: 21.02, *SD*: 1.25, range: 19–23) were all right-handed and had normal or corrected to normal vision.

Material

A total of 168 words were selected from the LEXESP database (Sebastián-Gallés, Martí, Carreiras & Cuetos, 2000): Half of the words had no higher frequency orthographic neighbor [Group 1, logarithm of the distance in word frequency to the closest less frequent neighbor (mean): 0.69; *SD*: 0.38] and half always had higher frequency orthographic neighbors [Group 2, logarithm of the distance to the highest frequent neighbor: 1.83; *SD*: 1.02]. In Group 2, target words had on average 3.02 higher frequency neighbors (*SD* = 1.43). The two groups of words did not differ in word frequency (log transformed) [Group 1: 0.81, *SD*: 0.27; Group 2: 0.83, *SD*: 0.28; $F(1, 83) = 0.2$, $MSE = 25.172$] or number of letters [Group 1: 5.09, *SD*: 0.72; Group 2: 5.10, *SD*: 0.71; $F(1, 83) = 0.32$, $MSE = 0.006$]. All words were bisyllabic; syllable structure and first syllable length [Group 1: 2.59, *SD*: 0.8; Group 2: 2.59, *SD*: 0.67; $F(1, 83) = 0.04$, $MSE = 16.583$] were controlled for between groups, as well as logarithm of phonological syllable frequency [Group 1: 3.13, *SD*: 1.65; Group 2: 3.25, *SD*: 1.83; $F(1, 83) = 0.17$, $MSE = 7.529$].

For each word we created two sentence contexts: A semantically constraining context, in which the target word was highly predictable (high-cloze context), and a semantically non-anomalous context, in which no specific word was predictable (low-cloze context). The critical word was presented in position 9.3 of sentences on average. Cloze-probability was assessed with a questionnaire presented to a group of 60 university students. Cloze-probability in the high-cloze contexts was 0.71 (*SD*: 0.24) without statistical differences between the two groups of target words, $F(1, 83) = 0.32$, $MSE = 759.491$. Average cloze-probability in the low-cloze contexts was 0.07 (*SD*: 0.04), showing that target words were not predictable; no differences between target word Groups 1 and 2 emerged either, $F(1, 83) = 0.01$, $MSE = 0.145$. We compared four experimental conditions crossing neighbor frequency (target words with higher frequency orthographic neighbors: *N-Freq higher* vs. target words without higher frequency orthographic neighbors: *N-Freq lower*) and cloze-probability (*High-cloze* vs. *Low-cloze*) manipulations. We then created two separate lists so that participants saw for each group half of the stimuli in a low-cloze and half in a high-cloze context.

Procedure

Each participant was seated in a silent room. Words were displayed on a monitor (maximum visual angle 5°) in white letters on a dark-gray background. Each word was presented for 300 ms, followed by a 300-ms blank screen. Sentence order was randomized and, every five sentences on average, participants were asked to answer a YES/NO comprehension question using keyboard buttons.

Electroencephalograph (EEG) recordings and analysis

EEG was recorded through a 32-channels BrainAmp system. Twenty-eight Ag/AgCl electrodes were arranged on an EasyCap recording cap based on the 10–20 International System. Additional external electrodes of the same material were placed on mastoids A1, A2 and around eyes Ve1, Ve1, He1, He2. Monopolar differential recording was referenced to the left mastoid. Impedance was kept below 5 kΩ for mastoid and scalp electrodes, and below 10 kΩ for EOG electrodes. Data were acquired at a sampling rate of 250 Hz.

EEG signal was offline filtered with a bandpass Butterworth filter (0.25–30 Hz) and then re-referenced to the right mastoid. Epochs of interest were selected time-locked to the target word presentation (–200 to 800 ms). After baseline correction (–200 to 0 ms), epochs were visually inspected to eliminate segments containing artifacts. On average 6.8% of epochs were rejected, without statistical differences among conditions ($F < 1$). We then calculated single-subject ERPs for each condition, which were used to calculate grand-averaged ERPs across subjects.

We considered two statistics patterns (Greenhouse-Geisser corrected). The *Midline* ANOVA considered three factors: Electrode (three levels: Fz, Cz, Pz), Neighbor Frequency (words with Lower Frequency Neighbor vs. with Higher Frequency Neighbor), cloze-probability (High vs. Low). The lateralized electrode ERP activity was evaluated through statistics on *Clusters* of electrodes: Left Anterior (mean activity of Fp1, F7, F3, FC5), Right Anterior (Fp2, F8, F4, FC6), Left Central (T7, FC1, C3, CP1), Right Central (T8, FC2, C4, CP2), Left Posterior (CP5, P7, P3, O1), Right Posterior (CP6, P8, P4, O2). The Clusters ANOVA considered four factors: Hemisphere (Left vs. Right), Region (three levels: Anterior, Central, Posterior), Neighbor Frequency and cloze-probability. Post-hoc comparisons were planned mainly for highlighting the Neighbor Frequency effect, since we expected a robust main effect of cloze-probability.

We also evaluated the *onset* of the effects emerging in the Midline ANOVAs described above by running those analyses in smaller windows of 100 ms shifting through the whole epoch in steps of 50 ms.[3]

RESULTS

Behavioral data

Participants answered comprehension questions with an overall accuracy of 91%, with no difference across conditions.

ERPs

Visual inspection of the ERPs revealed the largest N400 in central and parietal electrodes, showing that our effect has the classical distribution (Figure 1).

The differential effect reaches its negative maximum at 400 ms, i.e., affecting the N400. It is evident that the largest effect is due to cloze-probability, with the two low-cloze conditions being more negative compared to the two high-cloze conditions. Neighbor Frequency also affects the N400, as evident from the comparison between the two low-cloze conditions: When the critical word has higher frequency orthographic neighbors, the N400 is larger compared to when the target word has no higher frequency neighbor. In contrast, no reliable N400 difference is visible for the comparison between the two high-cloze conditions. Differently from what we expected, visual inspection suggests also an earlier onset for the cloze-probability effect, around 200 ms, compared to the Neighbor Frequency effect, emerging around 300 ms.

Based on visual inspection, we statistically evaluated the effects evident in the grand-average focusing on the mean voltages in the 200–600 ms[4] time window across subjects. A main effect of cloze-probability emerged in this time window [Midline analysis: effect size: 2.15 μV, $F(1, 23) = 48.597$, $MSE = 5.229$, $p < .001$; Clusters analysis: effect size: 1.41 μV;

[3] In other words, each time interval started 50 ms later than the previous one: first interval: 0–100 ms; second interval: 50–150 ms; third interval: 100–200 ms; and so on. Overlapping time windows could give a smoother evaluation of the ERP onsets.

[4] We selected this time window based on visual inspection (as also evident in the latency analysis); however, we evaluated our effects with more conventional time windows used for the N400 statistical analysis (for example 200–500 or 300–500 ms), obtaining the same pattern of results.

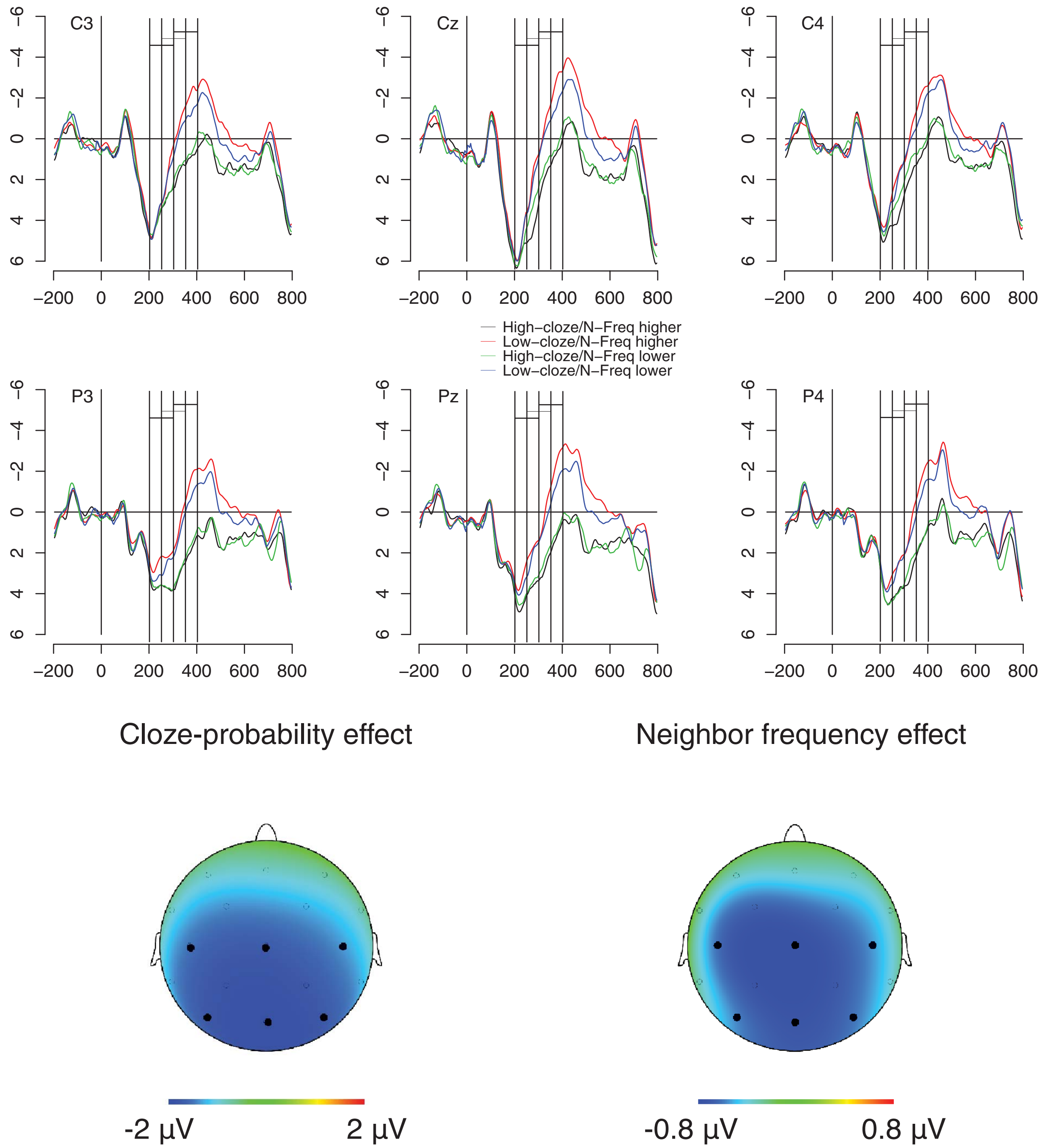

Figure 1. ERPs elicited by the target words in the four experimental conditions at six central-parietal electrodes. Black line represents words with neighbors of higher frequency presented in the high-cloze context; red line represents words with neighbors of higher frequency presented in the low-cloze context; green line represents words with no higher-frequency neighbors presented in the high-cloze context; blue line represents words with no higher-frequency neighbors presented in the low-cloze context. Negative values are plotted up. Vertical lines (in the 200–400 ms interval every 50 ms) indicate the 100 ms time windows (200–300, 250–350 and 300–400 ms) reported in latency analyses described in the Results section. Below we report the ERP distribution of the effects (time window: 200–600 ms) for the cloze-probability effect (low-cloze conditions minus high-cloze conditions) on the left and the distribution of the same ERP effect sensitive to neighbor frequency (neighbors of higher-frequency conditions minus neighbors of lower-frequency conditions) on the right. Black spots indicate the six electrodes represented in the upper part.

TABLE 1
Critical *F*-values (*df*: 1, 23) in each time window that revealed significant results in the latency analysis

Time window (ms)	*Neighbor Frequency*	*Cloze-probability*	*Neighbor Frequency* Cloze-probability*
200–300	0.6^{ns}	4.97*	2.96^{ns}
250–350	0.01^{ns}	22.84***	3.89^{ns}
300–400	0.44^{ns}	36.56***	6.4*
350–450	0.06^{ns}	44.76***	4.3*
400–500	0.92^{ns}	51.69***	4.38*
450–550	1.02^{ns}	21.99***	4.35*
500–600	1.76^{ns}	9.72**	6.12*

Notes: not significant; *$p < .05$; **$p < .01$; ***$p < .001$.

$F(1, 23) = 49.577$, $MSE = 5.533$, $p < .001$] and an interaction between cloze-probability and both Electrode in the Midline analysis [$F(2, 46) = 12.22$, $MSE = 0.51$, $p < .001$], and Region in the Clusters analysis [$F(2, 46) = 8.248$, $MSE = 1.123$, $p < .01$]. In addition, an interaction between cloze-probability and Neighbor Frequency emerged [Midline analysis: $F(1, 23) = 6.175$, $MSE = 2.185$, $p < .05$; Clusters analysis: $F(1, 23) = 4.961$, $MSE = 2.471$, $p < .05$]. Planned post-hoc comparisons in the Midline electrodes showed a main effect of Neighbor Frequency (effect size across electrodes: 0.72 μV) for the low-cloze conditions at Cz [$F(1, 23) = 5.172$, $MSE = 1.18$, $p < .05$], and Pz [$F(1, 23) = 4.733$, $MSE = 0.745$, $p < .05$]. The same distribution for the Neighbor Frequency effect (effect size across Clusters: 0.63 μV) emerged also in the left posterior Cluster [Left Posterior: $F(1, 23) = 4.289$, $MSE = 0.592$, $p < .05$]).

The latency analysis (Table 1) showed that the cloze-probability effect was already significant in the 200–300 ms time interval, while no interaction with the Neighbor Frequency factor emerged. In the following time window (250–350 ms), the cloze-probability effect was more robust, while its interaction with Neighbor Frequency was marginally significant. Only in the following interval (300–400 ms) did the cloze-probability effect start to interact with the Neighbor Frequency effect. This last analysis confirms that the cloze-probability manipulation affects ERPs about 100 ms before the Neighbor Frequency manipulation.

DISCUSSION

The present investigation connects studies analyzing the recognition of words presented in isolation and studies focusing more on the integration of words in a sentence context. The finding of neighbor frequency effects in a sentence processing paradigm—offering a more natural reading context compared to the recognition of words presented in isolation—validates the corresponding ERP effects reported in the literature on visual word recognition (Debruille, 1998; see also Holcomb, Grainger, & O'Rourke, 2002) as a general feature of language comprehension. But our data also show that these ERP effects for word recognition strongly depend on the sentence context: Only when the context does not preactivate the target word does the frequency of its neighbors have an impact on the recognition process. We obtained a larger N400 for words with neighbors of higher frequency compared to words without only when the critical word was not contextually predictable. In contrast, high contextual predictability canceled out the N400 effect for the neighbor frequency manipulation. When a word is unexpected (similarly to when it is presented in isolation), the cognitive system may be forced to select that item among a group of candidates (orthographic neighbors); if other candidates are more frequent, this process is costlier, since these words would initially have a higher level of activation (Grainger & Jacobs, 1996). On the other hand, if a target word has already been preactivated by the preceding sentence context, it will be much more activated during the recognition process than any other candidate, and no competition occurs.

Finding a similar distribution for the ERP effects for both neighbor frequency and cloze-probability (Figure 1) does not strengthen the postlexical integrative view of the N400 (Brown & Hagoort, 1993; Holcomb, 1993). In fact, the neighbor frequency effect on the N400 could hardly be interpreted as reflecting difficulty in integrating a word in a context. Instead, manipulating the orthographic similarity of our targets with more or less frequent neighbors, we tap directly into bottom-up features of the process of visual word recognition. The (large) N400 effect present for the cloze-probability manipulation could therefore—according to a lexical approach—be explained by assuming that contextual information influences word recognition from early processing stages. An interesting interpretation of our findings follows from the *prediction* hypothesis: The facilitation of processing words in a sentence reflects the extent to which the context preactivates specific word properties, also at a prelexical stage of processing (see also DeLong, Urbach & Kutas, 2005; Van Berkum, Brown, Zwitserlood, Kooijman and Hagoort, 2005). This would be possible only if some target word information were *already* available during the whole recognition process.

In our data, the contextual N400 effect has its onset about 100 ms before the neighborhood frequency effect. In our opinion, the facilitation induced by the context cannot be considered exclusively *postlexical*, otherwise we would have found a later ERP onset for the contextual manipulation compared to the lexical one. On the contrary, the context facilitates word recognition even *before* lexical competition among whole word candidates starts. This view is supported by studies showing that the context can facilitate word recognition also at a phonological (prelexical) stage of processing (DeLong et al., 2005). These findings contradict pure bottom-up processing models of language comprehension (Forster, 1981; Norris, 1994), and support more interactive models (see, e.g., Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981) that assume top-down (contextual) information to affect earlier stages of visual word recognition.

The overall pattern of *interactive* effects suggests that both lexical and contextual information are handled by the same brain network. The observed latency differences do not necessarily contradict this view: Different types of information might just be available at distinct time windows. However, the onset lag between the two effects could also be interpreted as evidence for two different but interactive cognitive processes: The context-sensitive process starts earlier but interacts with lexical processing mechanisms in the N400 time window. Top-down contextual information could influence in an interactive way the ongoing processes at work during word recognition and, more generally, language comprehension. Many recent neurocognitive models (Halgren et al., 2002; Lau et al., 2008) in fact propose a frontal-posterior network for semantic processing, in which more anterior areas of the left hemisphere mediate the selection among linguistic candidate representations (also based on contextual information), which are stored and activated in more posterior temporal brain areas.

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