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Electrophysiological correlates of semantic anticipation during speech comprehension

Patricia León-Cabrera[a], Antoni Rodríguez-Fornells[a,b], Joaquín Morís[a,c,*,1]

[a] Cognition and Brain Plasticity Group [Bellvitge Biomedical Research Institute-] IDIBELL, l'Hospitalet de Llobregat, Barcelona 08097, Spain
[b] Department of Basic Psychology, Campus Bellvitge, University of Barcelona, Barcelona 08097, Spain
[c] Department of Psychology, University of Oviedo, Oviedo 33003, Spain

A R T I C L E I N F O

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A B S T R A C T

Words that are more predictable given a previous context show facilitated processing over low predictable ones. Such facilitation has been traditionally viewed as associated with reduced amplitudes in the N400 component. However, this effect is observed during the presentation of the target word, and it does not provide direct information about the prediction processes engaged before. To overcome this, we investigated neural correlates of anticipation prior to target words using an auditory paradigm. The semantic context of the sentences varied in the degree of contextual constraint, with sentences of high, low or no constraint. The final word presented could be either congruent –the best completion– or incongruent. We inserted a noticeable 1000 ms delay before the final word of a sentence. The ERP analysis of the delay period unveiled a slow potential, with an amplitude that was more negative as contextual constraint increased. We also observed a canonical N400 modulation to semantic fit and cloze probability, and we report, for the first time to our knowledge, a delay in the onset of the N400 effect for low levels of contextual constraint. This study provides novel electrophysiological data that contributes to the better comprehension of the processes involved in speech processing with evidence in favour of anticipatory models of language processing.

The complexity and vastness of human language contrast with the seeming easiness of interlocutors to understand and react to linguistic utterances. The solution to this paradox might lie in the brain's ability to predict upcoming events and prepare for their occurrence (Bar, 2007). From predictive-based models of language processing, the concept of prediction refers to the pre-activation of specific concepts or their features before they are perceived (Kutas et al., 2011). From this perspective, incoming contextual information and prior knowledge are interactively combined to guide the pre-activation of the most probable continuations to the unfolding speech, which might explain why words that are more predictable are read faster, more likely to be skipped when reading (Ehlrich and Rayner, 1981; McDonald and Shillcock, 2003) and better decoded under circumstances of degraded speech (Clos et al., 2014; Miller et al., 1951).

Electrophysiological evidence coming from ERP studies of the N400 component has been a very important tool for prediction-based theories in language. The N400 (Kutas and Hillyard, 1980) is a negative-going voltage deflection peaking approximately 400 ms after the onset of any potentially meaningful word (Kutas and Hillyard, 1984). On experimental grounds, the predictability of words is usually operationalized as cloze-probability– the percentage of individuals that supply that word as a continuation of a particular sentence (Taylor, 1953). The cloze-probability of a word depends on the degree of constraint of its preceding context. Highly constraining contexts typically have a best completion with a much higher cloze-probability than any other continuation (e.g. "The dentist proceeded to clean her... *teeth*") while low constraining contexts have more than one likely continuation (e.g., "The meeting was arranged for the... *morning*/*afternoon*/*evening*") and their cloze-probabilities are lower. Importantly, the amplitude of the N400 follows a graded function that is negatively correlated with the cloze-probability –i.e. predictability– of the eliciting word given the preceding context (DeLong et al., 2005; Federmeier et al., 2007; Kutas and Federmeier, 2011; Kutas and Hillyard, 1984; Van Petten et al., 1999;). From the perspective of *active prediction models*, the N400 amplitude reduction to words with higher cloze-probabilities is an evidence of word processing facilitation as a consequence of successful word pre-activation. However, it is also possible to explain the reduced N400 amplitude in the absence of

* Corresponding author at: Departamento de Psicología, Universidad de Oviedo, Oviedo 33003, Spain.
E-mail address: joaquin.moris@gmail.com (J. Morís).

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predictive processes. Other authors have argued that it is more effective to passively wait until words are correctly identified rather than to anticipate them, given that in language there are usually an infinite number of potential continuations to the same sentence, making prediction an unviable strategy (Jackendoff, 2001; Morris, 2006). Language would be processed in a bottom-up, stimulus-driven fashion (see Altmann and Steedman (1988), Marslen-Wilson and Tyler (1980), Van Berkum et al. (1999) for discussions) and the context and other top-down influences would exert their influence only after complete word identification. From the perspective of *passive integration models*, the N400 modulation would merely reflect word integration processing costs upon their receipt, reduced for eliciting words that fit the prior context-based information better. This is referred to as the *active prediction* versus *passive integration* dilemma.

A way to disentangle the contribution of prediction and integration processes is to provide evidence of anticipatory activity preceding the identification point of the word that is being predicted (Kutas et al., 2011). In line with this idea, DeLong et al. (2005) used the fact that, in English, the *a/an* indefinite articles are functionally and semantically identical and are alternated only as a function of whether the initial phoneme of the noun they precede is a consonant (calling for "a") or a vowel (calling for "an"). Contrary to passive integration theories, they found that indefinite articles that were inappropriate given the expected word elicited larger N400 responses, suggesting that individuals were making predictions about the words and that those predictions were supported or violated as soon as the article was encountered, this is, before the actual word was perceived (see also, for variants of this paradigm, Van Berkum et al., 2005; Wicha et al., 2003). Similarly, studies of the time-course of spoken word identification show that the N400 congruity effect (divergence in the ERP between congruent and incongruent words) begins 200 ms prior to the eliciting word's isolation point – before it differs completely from any other congruent candidate word that starts in the same way (Van Petten et al., 1999). Also, in a recent magnetoencephalograpy experiment (Dikker and Pylkkänen, 2013), picture primes were used to manipulate contextual constraint. The pictures did or did not allow the prediction of specific nouns (i.e., the picture of an apple was predictive only of this concept but a picture of a grocery bag was predictive of any fruit). After the prime, the word "the" followed by a noun was presented and it could match or mismatch the prediction. They found that predictive primes triggered an enhanced activation of a top-down network, and interpreted this as an evidence of word pre-activation at different levels.

All these results converge on the idea that language processing is not strictly stimulus-driven. Instead, individuals actively use contextual information and prior knowledge to prepare for upcoming words. From prediction-based models, the facilitation of candidates that hold semantic and functional similarities with the most expected word suggests that the pre-activation process is strongly influenced by how information is stored in long-term memory (Kutas and Federmeier, 2000). However, the type of content that is being pre-activated is still a matter of investigation, whether the complete representation is pre-activated or only some of its associated features (e.g., semantic or morphosyntactic features) (Brothers et al., 2015; Huettig, 2015, for a review; Lau et al., 2013).

Certainly, the aforementioned N400 component studies argue strongly in favour of prediction in language. However, the N400 component is observed when the target word has already been presented, and therefore it is a correlate of the word processing. Because of this, it does not provide direct information about the brain correlates of the anticipatory processes that might be taking place before the target word is presented. To the best of our knowledge, to date, there is only one study that might have provided some evidence of semantically-related anticipatory processes previous to the target word presentation in the language domain. Besson et al. (1997) reported two experiments in which high semantically constraining sentences (proverbs) and low semantically constraining sentences were used. In half of the trials, an unexpected 600 ms pause was inserted between the penultimate and the ultimate word of the sentence. In their first experiment they used visual stimuli presented at a slow pace (200 ms each, with a 500 ms SOA). They found that, during the pause, and therefore previously to the presentation of the final word, a *Contingent Negative Variation* (CNV) developed. This CNV had a higher amplitude in the low constraining sentences than in the high constraining sentences, this is, the former had more negative voltages than the latter. According to the authors, the rather slow rate of word presentation could have provided participants with sufficient time to anticipate the final word much before its occurrence. Therefore, the CNV reflected the amount of expectancy towards the final word, more positive for more predictable continuations.

In their second experiment, Besson and colleagues used natural speech as stimuli. In this case, the analysis of the pause period also revealed more negative voltages in the low constraining sentences than in the high constraining sentences. However, instead of a sustained CNV, they obtained a marked emitted potential. According to the authors, the pause was more salient in the auditory modality because it strongly disrupted the temporal cadence of natural speech. Therefore, the emitted potential reflected surprise to the sudden interruption. This surprise would have been larger for high constraining sentences, where highly expected continuations were suddenly unfulfilled than in the case of the low constraining sentences.

Slow negative potentials, such as the CNV, have been systematically observed in other domains and are known to reflect anticipatory attention for upcoming relevant events (Brunia and Van Boxtel, 2001; Brunia et al., 2011a, 2011b). In particular, the CNV (Walter et al., 1964) is a negative slow brain potential, also known as the "expectancy wave", that shows up if a warning signal announces that, imminently, another stimulus will arrive, requiring some response. The CNV can be subdivided into two phases (Connor and Lang, 1969), an early phase (CNVe) that immediately follows the warning signal, and the terminal phase (CNVt) that is comprised by the *Readiness Potential* (RP) and the *Stimulus Preceding Negativity* (SPN) (Brunia et al., 2011b; Van Boxtel and Brunia, 1994). The SPN is another slow ERP component that progressively increases in amplitude as subjects are waiting for a stimulus that provides relevant information, such as performance feedback, instructions or affective stimuli (Van Boxtel and Böcker, 2004). Also, in learning paradigms, the amplitude of the SPN varies as learning advances (Morís et al., 2013) –that is, as future events become more predictable. In this experiment the voltage of the SPN became more positive as the incoming feedback became more predictable. Given all this, and the results obtained by Besson et al.'s (1997) results, slow brain potentials are good candidates for direct correlates of anticipatory processes in language comprehension.

The goal of the present study is to investigate if a slow component-like can be consistently observed before word perception and, if this is the case, to determine to what extent it might be a correlate of context-based word anticipation. To do so, we used an auditory delay paradigm. We presented participants semantic contexts of varying semantic constraint. Semantic contexts were either high (HC) or low (LC) constraining, and we included a non-semantic condition (NS) that did not provide a meaningful context. Importantly, a 1000 ms silent delay was inserted prior to the final word of each sentence. As already described, a similar study reported the development of a slow potential in the visual but not in the auditory modality (Besson et al., 1997). Nevertheless, we hypothesized that, with an appropriate control of the variables detailed hereafter, a component reflecting the proposed anticipatory process should be observed regardless of the sensory modality. Crucially, we presented the delay systematically in all trials, in contrast with the procedure used by Besson et al. (1997), in which only half of the sentences had a delay. By presenting this delay in all the trials we removed possible surprise effects due to an unexpected speech disruption. Another difference was that, in contrast with Besson et al.

(1997), all of the sentences employed were novel constructions, controlling for the differences in the familiarity of the sentences.

As a consequence of controlling the aforementioned variables, any difference in the electrophysiological response observed during this delay should be exclusively due to differences in the contextual constraint of the sentence, without any of the confounds that were present in previous experiments. We hypothesized that a slow potential reflecting anticipation would develop during the delay and that its amplitude should vary proportionally to how much information the context provided about the upcoming word. That is, its amplitude should be modulated as a function of the contextual constraint of the sentence. If we observe a modulation of an ERP component during the delay that develops prior to the target word and that is sensitive to the semantic constraint of the sentence, it would be an excellent candidate for a correlate of semantic anticipation, while providing additional support for prediction-based models in language processing. Additionally, we manipulated the congruency of final words in the HC and LC conditions and measured the N400 component that they elicited.

1. Method

1.1. Participants

Twenty-two right-handed young adults (12 females, M_{age} =21 years, *SD* =1.8, age range =18–24), were paid to participate in the experiment after giving written consent. None of the participants reported health problems or previous neurological disorders. Participants had normal hearing and normal or corrected-to-normal vision. All participants were native Spanish speakers and were on the course of completing or had already completed a higher-level education degree. The study was approved by the Ethics committee of the Hospital Universitari de Bellvitge.

1.2. Procedure

Participants were comfortably seated in front of a computer screen placed 70 cm away from them. After electrode application, headphones were placed over the cap. Participants were informed that they would listen to sentences disrupted by a short pause before the final word. They were told to pay special attention to the final word because they would have to complete a memory recognition test at the end of each block. Finally, they were briefed on the importance of minimizing movement and were told to synchronize their blinks to the blinking signal presented on the screen during the experiment completion and to prevent them at other times.

1.3. Stimuli and Task

We designed an auditory delay paradigm in which participants listened to sentences of a varying degree of contextual constraint that had a 1 s silent pause before the presentation of the last word. A total of 392 sentences (176 highly constraining sentences, 176 low constraining sentences and 40 non-semantic sentences) and 392 final words were used as stimuli. Of those words, 176 were congruent final words – the best completion of the sentence–, 176 were incongruent final words, and 40 were neutral words for the non-semantic condition (Table 1). We used the materials from Mestres-Missé, Rodríguez-Fornells and Münte (2007), who created and categorized sentences in Spanish, that were either low constraining (mean cloze probability 6.1 ± 10.3% standard deviation), or highly constraining (mean cloze probability 76.0 ± 17.7% standard deviation). The final words to the sentences were always nouns. For the non-semantic condition (NS) we randomly picked 40 sentences from the low contextual constraint condition and scattered the vowels of each word so that they were completely unintelligible but still preserved the grammatical structure.

Table 1
An example of the four potential combinations of sentence type and final word type and an example of a non-semantic sentence (Spanish original sentences are included below). High and low-cloze probability conditions were counterbalanced because each final word (either congruent or incongruent) fell both into the high or low-cloze category depending on which sentence type they followed.

Example Sentences	*Constraint-Congruence Combination*
After lunch I almost always smoke two *cigarettes* (Después de comer casi siempre fumo dos *cigarrillos*)	High constraint-Congruent
María really hates the smell of *cigarettes* (María detesta mucho el olor de los *cigarrillos*)	Low constraint-Congruent
The goalkeeper managed to catch the *shore* (El portero fue capaz de atrapar la *orilla*)	High constraint-Incongruent
As a present she gave her son a *shore* (Le ha regalado a su hijo una *marea)*	Low Constraint-Incongruent
Tehtod no tehykstusmeb o *trip* (Tehtod no tehykstusmeb o *viaje)*	Non-Semantic

The incongruent final words were obtained from the ESPAL database (Duchon et al., 2013), a Spanish corpus of lexical stimuli, matching the congruent words in length, number of syllables and frequency. All the linguistic stimuli were transformed into audio using a voice-synthesizer software (Loquendo TTS Director, 2005). This software creates natural-sounding audio, very close to natural speech, while allowing precise control of the speech rate, the amplitude and the prosody of the speech (see Supplementary materials for a sample sentence of each condition). After audio conversion, the first part of the sentences had a mean duration of 1966 ms (*SD* =288) with similar means in each condition (HC =2000 ms, LC =1925 ms, NS =1992 ms). The final words had a mean duration of 490 ms (*SD* =122) with similar durations across conditions (mean durations: Congruent =485 ms, Incongruent =494 ms, Neutral =495 ms). The experiment was divided into 10 blocks of 20 sentences in which 20% were non-semantic sentences, 40% highly constraining sentences and 40% low constraining sentences (within the conditions of sentences with semantic content, half ended with a congruent word and half with and incongruent word). Each block lasted approximately 2.5 min (*M* =8456 ms). Within each block, the order of the sentences was random.

The task proceeded as follows (see Fig. 1). A fixation point (a cross) remained on the screen from the beginning until the end of the trial. Two seconds after the presentation of the fixation point, participants listened to a sentence that included a 1 s delay before the presentation of the final word. Then, they waited for 1 s until the blinking signal appeared (a picture of an eye presented at the center of the screen). The blinking signal remained for 2 s before the next trial began. With the objective of ensuring that participants paid attention to the relevant stimuli, a memory recognition test followed each block. In this test, ten words were presented visually one at a time; half were final words previously presented and half completely new ones. Participants had to respond, pressing a key, whether they had heard the word in the block or not. Before the start of the task, an instruction screen indicated the correspondence between "z" and "m" keys and “yes” and “no” answers, counterbalanced across participants. Once the memory recognition task began, each word remained on the screen until an answer was supplied, followed by a 600 ms fixation cross until the next word appeared. At the end of the memory task the next block started right away, except for even numbered blocks that were followed by a pause that could be resumed anytime.

For the purpose of this study, we were particularly interested in controlling for potential confounds in the contextual constraint manip-

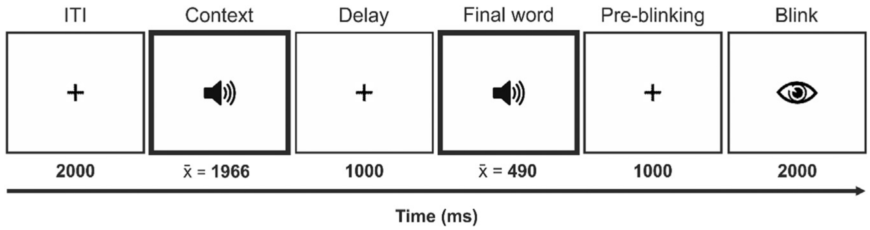

Fig. 1. Step-by-step depiction of a trial. In each trial, participants listened to a sentence that had a 1000 ms silent delay inserted before the presentation of the final word. After the presentation of the final word, a signal announced participants that they could blink. Each block included 20 trials and each participant completed a total of 10 blocks.

ulation. To do that, each HC sentence was paired with a LC sentence that shared the same congruent and incongruent final words (for instance, both the highly constraining sentence "I have never flown on a…" and the low constraining sentence "The dot in the sky must be a…" shared "plane" as their congruent ending and "drink" as their incongruent). Therefore, across subjects, final words did not change their congruence category ("plane" was always congruent and "drink" was always incongruent) but they changed their cloze-probability value depending on which sentence type (HC or LC) they randomly followed. Within subjects, the combination of a particular sentence type and final word type was randomly picked in each trial, and once a specific combination was presented (i.e., "I have never flown on a… *plane*"), the other three remaining potential combinations of the same pair were excluded from selection for the same participant. As a result, the high and low constraint effects were completely counterbalanced across subjects because every final word was equally used as a low and high-cloze ending. Moreover, although the congruence categories remained invariant across subjects, every pair of congruent and incongruent words (i.e. "plane" and "drink") were matched in word length, word frequency, familiarity, imaginability and concreteness.

In the case of the NS condition, each final word was matched with the corresponding congruent and incongruent pair of its scattered sentence. For example, if the sentence used for scattering was "The dot on the sky must be a…" and final word pair was "plane" and "drink", then final word "trip", matched in the variables mentioned before, was used for the non-semantic condition.

1.4. Electrophysiological recording

The electroencephalographic signal (EEG) was recorded from 31 scalp electrodes placed at standard positions of the 10–20 system (electrode positions: Fp1/2, Fz,F3/4, F7/8, FCz, FC1/2, FC5/6, Cz, C3/4, T3/4, T5/6, CP1/2, CP5/6, Pz, P3/4, PO1/2, Oz, left and right mastoids) mounted in an elastic cap. Two electrodes placed below the right eye and 1 cm from its outer canthus registered respectively the horizontal and vertical electro-oculograms (EOG). Electrode impedances were kept under 3 kΩ when possible and always below 5 kΩ. The EEG was amplified with BrainAmps amplifiers (BrainProducts, München) with an online band-pass filtering of .015–1000 Hz and sampled with a frequency of 1000 Hz.

1.5. ERP data analysis

Data were re-referenced off-line to the average of the mastoid electrodes. Before the analysis, the data were filtered using a 50 Hz notch filter (to attenuate electrical line noise) and a 30 Hz low-pass Butterworth filter, with a roll-off of 12 dB/oct, as implemented in the ERPLAB toolbox V4.0 (López-Calderón and Luck, 2014). An additional 8 Hz filter was applied to the figures presented. We applied Mestres-Missé et al. (2007) criteria for trial rejection: all epochs with an activity over ± 85 μV in the ocular channel or ± 200 μV in any other channel were removed. Furthermore, after visual inspection, trials contaminated by blinks, excessive muscle activity or big drifts were eliminated. The percentage of trials included after the rejection was not significantly different between conditions of contextual constraint (HC, M =93.9%; LC, M =95.2%; NS, M =94.77%; F(2,42) =1.031, p=.36, η_p^2 =.04) or between conditions of the final words (HC congruent, M =96.2%, HC incongruent, M =96.4%; LC congruent, M =97.4%; LC congruent, 96.4%; Neutral =96.6%; F(4,84) =4.277, p=.68, η_p^2 =.027).

The analysis was carried out in two different parts. The first focused on the activity in the delay period between the initial portion of the sentence and its final word. The epochs for this analysis were time-locked to the onset of the delay, ranging from −100 to 1000 ms. The 100 ms pre-delay interval served as baseline. For this analysis, the target time window was the final 200 ms of the delay at fronto-central sites. This selection was made a priori and it was based on the results and analysis protocol of Morís et al. (2013). In a similar paradigm, although non-linguistic, they showed that changes in the SPN increased over time and that the effect was maximal right before the presentation of the expected stimulus, as it had already been described in the literature (see Brunia et al. (2011a) for a review). To provide additional evidence of the robustness of the effect, another set of analyses was carried out using a baseline going from 0 to 100 ms post-onset of the delay (see Supplementary materials).

The second analysis, corresponding to the N400, was time-locked to the onset of the final word and included the time window from −100 to 1000 ms, the baseline being the 100 ms pre-stimulus. In this case, we used standard N400 parameters. The time window selected ranged from 300 to 500 ms, and we analyzed the Pz electrode (e.g., Mestres-Missé et al., 2007). An additional analysis of the N400 component using a cluster of central-posterior electrodes was also carried out (see Supplementary materials).

After baseline correction, we computed the average for each subject and condition in each analysis separately. Statistical analyses were run with SPSS 21. All the Linear Mixed Model analyses were run using an autorregressive matrix of covariance.

2. Results

2.1. ERPs during the delay

A first negative potential peaked approximately at 160 ms after the onset of the delay, followed by a slow potential, starting approximately at 200 ms, which developed from that moment to the end of the delay (see Fig. 2).

A Linear Mixed Model analysis was conducted on the mean amplitudes of six frontal and fronto-central electrodes, on right (F8 and FC6) central (Fz and FCz) and left (F7 and FC5) locations within the 800–1000 ms time window after the onset of the delay. We included three factors: Condition (3 levels, HC, LC and NS), Laterality (3 levels, right, central and left) and Position (2 levels, frontal and fronto-central). The model yielded a significant effect of Condition (F(2, 248.62) =41.657, $p < .001$). Post hoc t-tests for related samples showed significant differences between the three conditions ($p < .05$ in all the comparisons). The size of voltage amplitudes increased in a scaled fashion with HC as the most negative condition (M =.52 μV), followed by LC (M =1.14 μV) and NS as the most positive (M =2.09 μV). Specifically, the mean voltage of HC was significantly

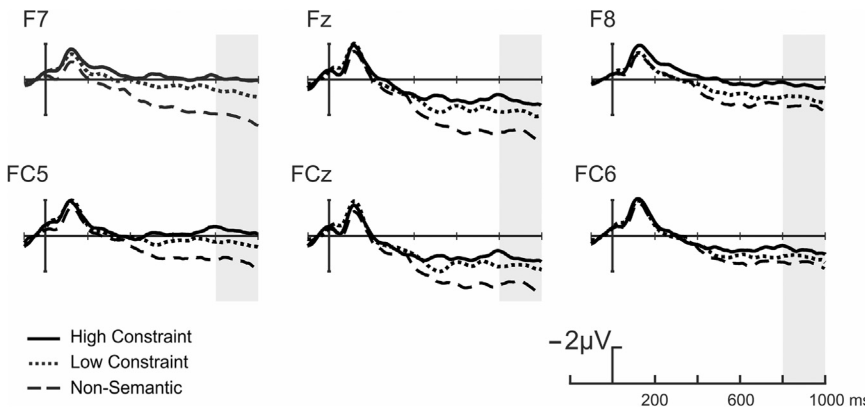

Fig. 2. Grand averages at electrodes with left (F7, F5), central (Fz, FCz) and right (F8, FC6) locations showing the slow potential increasing along the interval and the changes in amplitude among conditions, high semantic constraint (HC), low semantic constraint (LC) and non-semantic (NS). Negative is plotted upward. A slow increasing potential developed along the delay interval before the presentation of the final word. Following Morís et al. (2013) statistical analyses were conducted on the 800–1000 ms time window, shadowed in grey in the figure.

smaller than the mean voltages of the LC condition (p=.001, 95% CI of the difference [.28, .95]), and of the NS condition ($p < .001$, 95% CI of the difference [1.23, 1.91]). At the same time, the mean of LC was smaller than the mean of NS ($p < .001$, 95% CI of the difference [.623, 1.29]).

The Laterality main factor was also significant (F(2, 119.17) =11.71, $p < .001$), but not the Position factor, neither their interaction or any of the interactions involving the Condition factor (p > .182 in all of the cases).

The scalp distribution of the differences between conditions, for the same 800–1000 ms time window is depicted in Fig. 3. The topographic maps of the bottom row show the differences between mean voltages of HC and NS, with a frontal and fronto-central distribution and a tendency to larger amplitudes in the left hemisphere. The topographic maps at the top row represent the mean voltage differences of HC and LC, smaller but still significant. They are also maximal at left frontal and fronto-central sites. As mentioned before, voltage becomes more positive as the sentence's cloze-probability decreases, being the most negative for HC and most positive for NS.

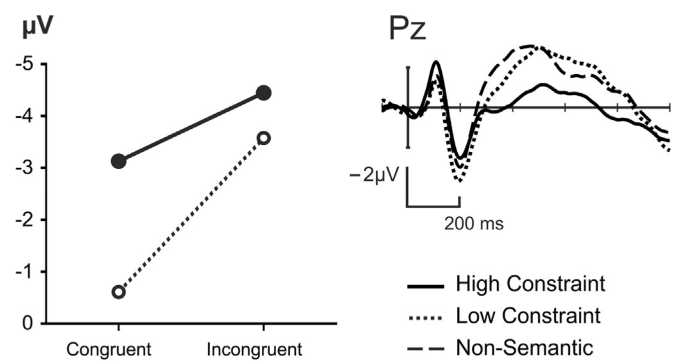

Fig. 4. *Left panel.* Plot of the mean N400 amplitude values of the significant interaction Semantic Constraint x Congruency. *Right panel.* Grand averaged ERPs for the Pz electrode elicited on congruent endings of high semantic constraining (HC) and low semantic constraining (LC) sentences, along with the final words of non-semantic (NS) sentences. A smaller N400 effect is observed in HC congruent endings compared to LC congruent and NS endings.

2.2. N400 effects

A Linear Mixed Model was performed on the Pz electrode using the time window of 300–500 ms from the onset of the final word (see Fig. 4) (Mestres-Missé et al., 2007), with Contextual Constraint (2, High and Low) and Congruency (2, Congruent and Incongruent) as factors. The analysis revealed significant main effects of Contextual Constraint (F(1,83.334) =15.21, $p < .001$) and Congruency (F(1,56.77) =48.54, $p < .001$). The Contextual Constraint × Congruency interaction was also significant (F(1,60.92) =5.51, p=.022) (see Fig. 4, left). Post-hoc tests revealed that incongruent endings to the HC condition produced larger amplitudes (M =−3.6) than congruent endings (M =−.62) ($p < .001$, 95% CI of the difference [2.05 3.92]), just as the amplitude of incongruent endings to the LC condition (M =−4.49) was larger than that of congruent endings (M =−3.16) (p=.006, 95% CI of the difference [.40 2.27]). Within congruent endings, the mean voltage of HC congruent was significantly more positive than LC congruent ($p < .001$, 95% CI of the difference [1.42 3.66]), while LC incongruent was not significantly different from the HC incongruent (p=.117, 95% CI of the difference [−.23 2.01]). An additional analysis using a cluster of four electrodes (Cz, CP1, CP2 and Pz) showed the same pattern of results (see Supplementary Material) (Fig. 5).

The incongruent minus congruent difference waveforms were

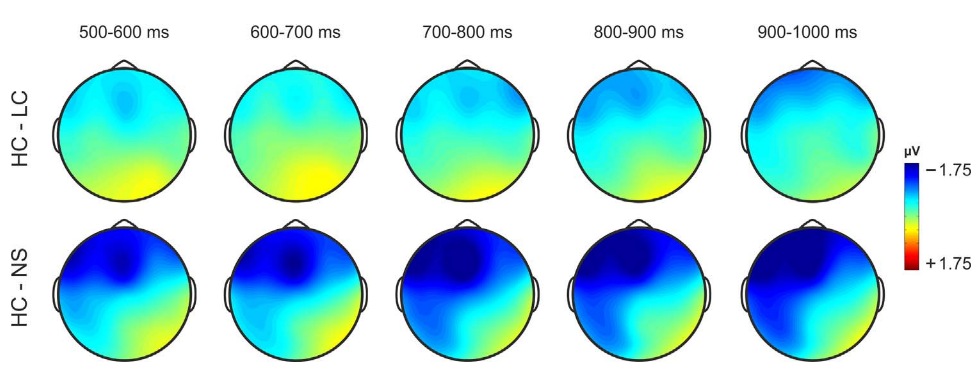

Fig. 3. Topographical maps of the mean voltage differences between high semantic constraint (HC) and low semantic constraint (LC) conditions (top) and between HC and non-semantic (NS) conditions (bottom) for the mentioned time window. The range of voltage values for the maps is ± 1.75 μV.

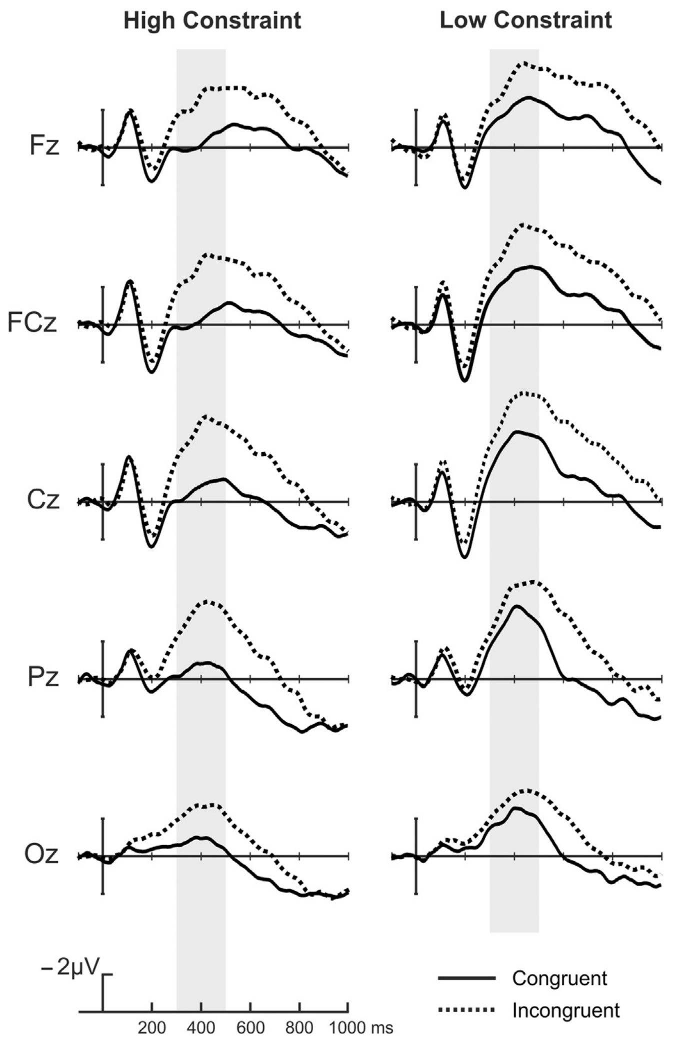

Fig. 5. Grand averaged ERP waveforms in the 1000 ms following the offset of the final word (all midline electrodes, Fz, FCz, Cz, Pz, Oz) for all semantic conditions. The grey area corresponds to the 300–500 ms time window where the N400 effect was analyzed. A negativity (N400) was elicited, especially on parietal and central sites.

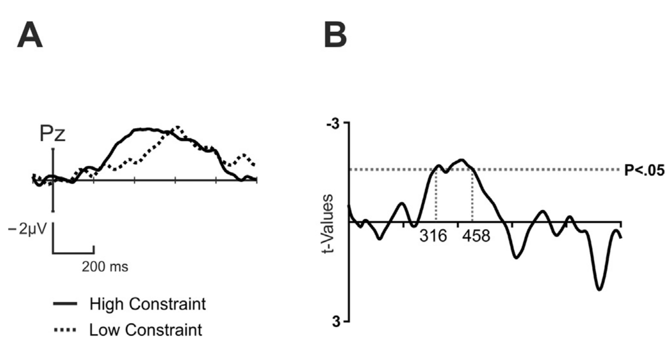

Fig. 6. *Panel A.* N400 difference waveforms (incongruent - congruent) for each semantic constraint condition at the Pz electrode. *Panel B.* Difference waveforms of *t*-value evolution of the differences between the two waves. The grey dotted line indicates the point at which the waves start to differ (316 ms, t-value =−2.46, p < .05) according to our criteria to determine onset latencies.

obtained for both Contextual Constraint conditions (see Fig. 6, left panel) on the Pz electrode. Onset latency was computed and then subjected to statistical analyses. Following the procedure of Rodríguez-Fornells et al. (2002), onset latencies were calculated via a stepwise series of *t*-tests (step size =4 ms). For each test, data from a time-window of 50 ms were averaged (i.e., point of measure ± 25 ms) in the full 1000-ms period after the final word onset. Onset latency was defined as the point at which four consecutive *t*-tests showed a significant difference from zero ($p < .05$). The difference wave for HC endings diverged from baseline from 265 to 877 ms (for a 612 ms duration, $2.69 < t(21) < 5.54$) and the difference wave for LC endings diverged from baseline from 346 to 817 ms (a duration of 471 ms, $2.06 < t(21) < 7.04$). A comparison between the difference waveforms of the two conditions revealed significant differences between 316 to 348 ms and then from 369 to 458 ms (a total duration of 89 ms, $2.07 < t(21) < 2.49$) (see Fig. 6., right panel).

The topographical mapping of the temporal evolution of the congruency effect also evidences the latency difference (see Fig. 7) and reveals a typical centro-parietal distribution of the N400 (Kutas and Hillyard, 1984).

3. Discussion

This study investigated correlates of prediction-related processes during speech processing taking place before the presentation of the target word. To accomplish this goal, we inserted a constant 1 s delay between the penultimate and the final word of a sentence. The semantic context of the sentences varied in the degree of contextual constraint, establishing high, low or no expectancy towards the final word, which could turn out to be congruent –the best completion– or incongruent. The ERP analysis during the delay period unveiled a slow potential, with an amplitude sensitive to the level of contextual constraint, being more negative as contextual constraint increased. After the presentation of the final word of the sentence, we observed a canonical N400 modulation to semantic fit and contextual constraint and we found a delay in the onset of the N400 effect for low levels of contextual constraint.

First, we will focus on the main similarities and differences between the slow potential reported and the SPN. The SPN is typically elicited in motivation and learning paradigms whenever a delay is introduced prior to the occurrence of motivationally relevant stimuli (e.g., monetary rewards, performance feedback, evocative photos, or painful stimuli) which are expected (Brunia et al., 2011a; Damen and Brunia, 1987; Kotani et al., 2015). In these studies, the SPN is interpreted as an index of expectancy, as its amplitude usually becomes more positive with increasing levels of expectancy or predictableness of the upcoming stimuli (Kotani et al., 2003; Morís et al., 2013). Similar to the SPN, the amplitude of the slow potential reported here follows a graded order that is consistent with the differences in the level of expectancy that each condition establishes toward the final words, as well as a progressive amplitude increase in time (Walter et al., 1964; Brunia and Damen, 1988) and a mainly fronto-central distribution (e.g., Mattox et al., 2006; Morís et al., 2013; Hackley et al., 2014). However, an important difference is that the voltage pattern is the inverse compared to the previous reports of SPN. The amplitude in the slow potential we report is more negative for expected stimuli, instead of more positive. In that respect, most descriptions of the SPN to date come from tasks that use non-linguistic stimuli and that might entail distinct cognitive processes (see Brunia et al., 2011b, for a review) so the activation of a different cortical generator might explain this difference (Luck, 2012). The use of linguistic material with semantic content might also explain the apparent left-hemisphere dominance on fronto-central sites of the slow potential that we observed, which differs from the SPN's right-hemisphere preponderance that is sometimes observed (Damen and Brunia, 1987; Ohgami et al., 2004).

While the use of linguistic materials might be a significant factor in the direction of the effect, the voltage pattern cannot be attributed solely to this because it also differs in several language-related studies. In fact, in the domain of language, the available evidence on slow potentials is inconsistent so far. On the one hand, in line with our results, Kaan and Carlisle (2014) found a slow potential component with more negative amplitudes during the delay to predictive compared to random letter sequences, in a visual paradigm. On the other hand, as

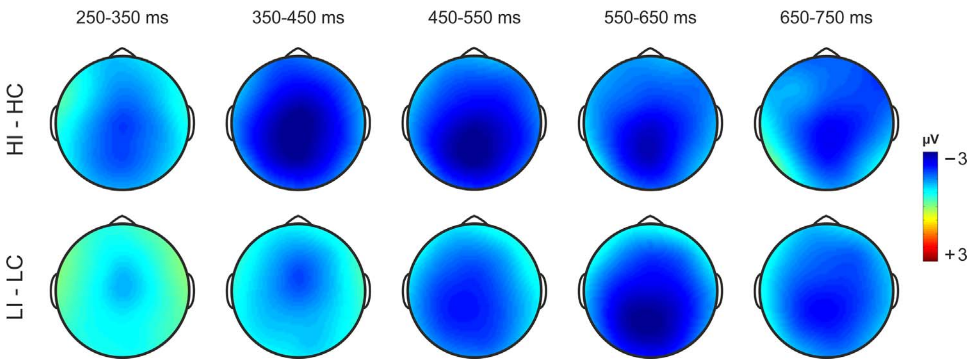

Fig. 7. Temporal evolution of the congruency effect for high (top row) and low (bottom row) cloze-probability endings. Spatial distribution of the differential voltage (incongruent - congruent) every 100 ms in the 250- to 750-ms time window. The topographical mapping evidences the earlier peak of the effect for high compared to low cloze-probability endings. The range of voltage values for the maps is ± 3 μV.

previously mentioned, a similar study by Besson et al. (1997) did not observe the development of a slow component in the auditory modality. We think that an experimental difference that might have allowed for the observation of the slow component in our case is the elimination of the surprise effect to the delay by introducing it in all the trials, instead of introducing it randomly and only in half of them. Then, in the visual modality, Besson and colleagues' found a slow potential but they encountered more negative amplitudes for sentences with a lower contextual constraint –that is, opposite to our findings–. One possibility is that the differences in the experimental paradigm –the type of manipulation, the nature of the anticipated stimuli, the duration of the anticipation interval, among others– activated different cortical generators of the slow potential (Kotani et al., 2015; Stravopoulos and Carver, 2014; Van der Molen et al., 2013) that might account for the distinct pattern. Firstly, one critical difference between the two studies is that our task was auditory instead of visual, although we already mentioned one study in the visual modality that is consistent with our observations (Kaan and Carlisle, 2014). Secondly, Besson and colleagues' used proverbs for the condition of high contextual constraint while we used novel sentences. Proverbs are fixed expressions in memory which might engage qualitatively different pre-activation processes compared to previously unheard sentences (Cacciari and Tabossi, 1988; Vespignani et al., 2010) which represent a more common situation and are the type of sentences that we used. On that point, the materials that we used in our experiment might be better suited in order to reveal how contextual information impacts natural language processing.

Altogether, comparable evidence is scarce and inconsistent in the domain of language. Despite this, in a more general sense, our finding matches previous descriptions of slow event-related potential modulations appearing in between relevant linguistic stimuli (Besson et al., 1997; Fiebach et al., 2002; Kaan and Carlisle, 2014; Kutas and Hillyard, 1980, 1984; Kutas et al., 1988) or across the course of a whole sentence (Münte et al., 1998; Nieuwland, 2015; Van Petten et al., 1991). The generally convergent observations in these ERP studies provide soundness to the interpretation that the slow potential we describe here might reflect language-related processes. In particular, given their similarities, the component we report here might be a modulation of the SPN. Further investigation is required to investigate to which extent the slow potential activity recorded here might reflect an expectancy-based process ubiquitous to other domains or a language-specific process.

Our results are in line with models of anticipatory language processing that state that contextual information is *not only* processed incrementally as the information unfolds in time but that the brain proactively uses top-down information to pre-activate upcoming words, or their associated features, and facilitate their processing upon receipt (Federmeier and Kutas, 1999; Kamide, 2008; Kutas et al., 2011 for a review, McClelland and Elman, 1986; Van Berkum et al., 2005; Van Petten et al., 1999; Van Petten and Luka, 2012). The amplitude modulation of the slow potential revealed that contextual constraint had an impact on cognitive processing even before the final word was perceived. In semantically meaningful conditions predictions would have been generated, producing different levels of expectancy –as a function of contextual constraint– towards the upcoming word. Consistently, we replicated the classical modulation of the amplitude of the N400 component to contextual constraint (Besson et al., 1997; Federmeier and Kutas, 1999; Federmeier, 2007; Kutas and Hillyard, 1984) and to the congruency of the completions of the sentence (DeLong et al., 2005; Kutas and Hillyard, 1983; Kutas and Federmeier, 2000; Van Petten et al., 1999).

We found an earlier onset of the N400 effect for high compared to low contextual constraint. This result is consistent with the idea that, as the contextual constraint increases, a larger number of lexical or/and semantic features associated to this specific context could be pre-activated (Boudewyn et al., 2015) and be straightforwardly compared with the actual bottom-up input. This would allow the detection of a mismatch sooner than in the case of low contextual constraint, where more than one lexical candidate might be pre-activated. In line with this result, Cermolacce et al. (2014) recently reported an N250 congruity effect for well-known familiar proverbs over unfamiliar sentences. In the case of proverbs, a perceptually-based representation of the specific upcoming word might be pre-activated causing an almost immediate perceptually-based mismatch when the input is incongruent. In our experiment we cannot attribute the onset difference to a congruency effect due to its confound with cloze-probability effects (congruent and incongruent words have more similar cloze probabilities in low than in the high contextual constraint conditions). Despite this limitation, the results in both studies are convergent and that they reinforce the interpretation of the N400 effect from prediction-based accounts.

A question that must be taken into account is whether the artificial introduction of a delay in the sentences might lead to the engagement of processes that would not work in natural speech situations. The delay might provide an unusually long time to generate predictions that otherwise might not have been formulated (Rayner et al., 2004). It would be desirable, for future experiments, to explore whether anticipatory processes –such as the slow potential that we report– are also elicited under more naturalistic circumstances. Another interesting approach for future studies would be to explore the possible relationship between the processes indexed by the reported slow potential and the well-known N400 component. Theoretically, if we interpret the reported slow potential as a correlate of prediction generation and the N400 component as an index of the level of mismatch between the predicted and the actual input, we would expect to find some degree of correlation between them. Our design did not allow us to test this possibility. Firstly, it would be necessary to use more than two levels of contextual constraint to allow matching a wider range of values of the two components. Secondly, in our task, the critical time window of the slow potential overlaps partially with the baseline of the N400 component. This is not a problem as long as the two components are interpreted separately but it could produce an autoregression effect that would distort any direct correlation between them.

Regarding the main goal of the study, we found an electrophysiological correlate that shows a modulation that is consistent with the idea that forthcoming words or their associated semantic features might be pre-activated prior to their perception. Due to its shape and timing, the slow potential cannot be a correlate of the processing of the target word itself and it must reflect the operations of processes that are engaged before the presentation of such word. Given these features, the classical confound in prediction-based conclusions of N400 component studies –that is, that any difference in brain activity merely reflects context-driven facilitation in word integration– does not apply for the current data. While the slow potential might capture integration processes of the preceding context, it cannot reflect integration processes of the final and potentially predicted word. Overall, the present study contributes with novel evidence that is convergent with prediction-based interpretations drawn from previous N400 component studies. Altogether, different ways of approaching the investigation of processes involved in spoken language comprehension provide results in favour of anticipatory processing in language. Exploring the nature of the neural correlates of anticipation processes will continue to enrich our view of classical effects and theoretical frameworks that are currently used to explain them.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neuropsychologia.2017.02.026.

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