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Electrophysiological correlates of semantic anticipation during speech comprehension

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ABSTRACT

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

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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 (pro-verbs) 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.