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Research Report

Perceptual facilitation of word recognition through motor activation during sentence comprehension

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ABSTRACT

Despite the growing literature on anticipatory language processing, the brain dynamics of this high-level predictive process are still unclear. In the present MEG study, we analyzed pre- and post-stimulus oscillatory activity time-locked to the reading of a target word. We experimentally contrasted the processing of the same target word following two highly constraining sentence contexts, in which the constraint was driven either by the semantic content or by the lexical association between words. Previous research suggests the presence of sensory facilitation for expected words in the latter condition but not in the former. We observed a dissociation between beta (~20 Hz) and gamma (>50 Hz) band activity in pre- and post-stimulus time intervals respectively. Both the beta and gamma effects were evident in occipital brain regions, and only the pre-stimulus beta effect additionally involved left pre-articulatory motor regions. Lexically constrained (*vs.* semantically constrained) words elicited reduced beta power around 400 msec before the target word in motor regions and a functionally related gamma enhancement in occipital regions around 200 msec post-target. The present findings highlight the role of the motor network in word-form prediction and support proposals claiming that low-level perceptual representations can be pre-activated during language prediction.

1. Introduction

The ease and speed with which language processing unfolds has been explained by the human ability to anticipate information about the incoming input (Federmeier, 2007; Friston & Frith, 2015; Levy, 2008; Lewis & Bastiaansen, 2015). Thus, while listening to or reading a text, the comprehender incrementally integrates internal semantic knowledge that in turn provides constraining information concerning the meaning expressed in the remaining part of the message. This process, however, has been poorly detailed from both cognitive and neurophysiological perspectives, with research often focusing more on the consequences of such anticipatory analysis (for discussion see Molinaro, Barraza, & Carreiras, 2013; 2016). The most consistent finding from this literature is that contextual information facilitates the lexical recognition of a predicted

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word, as evidenced by reduced evoked activity around 400 msec post-stimulus onset. This has led to the conclusion that the lowest representational level that top-down predictive processing can affect is the lexical/semantic level, i.e., an abstract representational level independent of the low-level formal properties of a stimulus. Nonetheless, the great majority of these studies employed regular compositional contexts, where predictions would be generated at the semantic level, probably through the pre-activation of specific semantic features or categories. As a consequence, lexical pre-activation could disperse to the semantic neighbors of the expected word (Federmeier et al., 1999) and not be strong enough to activate word-form-related sensory representations. In addition, semantic relatedness and lexical relatedness are not highly correlated, so activating semantic neighbors might be unrelated to activating lexical neighbors. However, in a recent set of studies (Molinaro et al., 2013; Monsalve, Pérez, & Molinaro, 2014; Vespignani, Canal, Molinaro, Fonda, & Cacciari, 2010), we took advantage of a qualitatively different relation between words in natural language, i.e., the lexical association (Hutchison, 2003, for a review). Associative relations reflect links between lexical items due to the number of co-occurrences in natural language. Sequences of words that co-occur in natural language more than would be expected by chance are broadly defined as multi-word units (MWU). These sequences are often recognized before the last word(s) of the string, so that given the initial fragment of the sequence, the predictability of the last word(s) is usually very high. In this scenario, the prediction would be generated directly at the lexical level, pre-activating the corresponding word-form features. No semantic dispersion would take place (if at all, dispersion would in this case involve orthographic neighbors) and the specific lexical item would have the "strength" to pre-activate word-form-related sensory representations. In Molinaro et al. (2013) we employed these stimuli to study language prediction: we compared the electrophysiological correlates of processing expected words following either a compositional (semantic) or a collocational (MWU) context. We reported early post-stimulus evoked electrophysiological responses around 120 msec to be reduced in the MWU condition compared to the semantic condition (even if in both conditions the context was highly constraining), suggesting facilitated visual sensory processing of word-forms in MWU. Furthermore, pre-stimulus oscillatory activity was related to this early post-stimulus effect. Phase-synchronization in the theta range (5–6 Hz) across the EEG signals was stronger for the MWUs compared to the semantic constraining condition. This effect was interpreted as reflecting differential processing cost in the generation of predictions. In a re-analysis of the Molinaro et al. (2013) dataset (Monsalve et al., 2014), we examined the oscillatory post-stimulus activity at the single-trial level, finding a positive correlation between cloze probability and gamma power (>50 Hz) for both conditions, but overall higher gamma for MWU compared to the semantic condition. This is congruent with other studies finding positive associations between gamma and predictability in language processing, which could result from a stronger perceptual binding between the expected internal representation and the actually encountered stimulus (Hermann et al., 2004; for a discussion; Lewis & Bastiaansen, 2015). While this would be the case for any highly constraining condition, the matching is always "greater" for MWU, which could arise from more perceptually-detailed expectations in this case. These constructions thus provide a unique opportunity to explore how sensory predictions unfold in the language domain.

Neurophysiological evidence on sensory processing points to a relevant role of brain oscillations in the interaction between internal expectations and the physical properties of the input. Distinct frequency bands have been implicated in the feedback propagation of predictions and feedforward propagation of prediction error (beta – 13–30 Hz – and gamma – > 30 Hz – respectively) through the processing hierarchy (among others: Arnal, Doelling, & Poeppel, 2015; Bastos et al., 2015; Richter, Thompson, Bosman, & Fries, 2017). However, in the language literature, support for this scheme is mixed (Lewis & Bastiaansen, 2015). Previous studies of prediction in language have provided support for a top-down role of beta oscillations, in line with the literature from sensory processing. Indeed, in Molinaro, Giannelli, Caffarra, and Martin (2017) we reported differential beta oscillatory activity (13–30 Hz) in a time interval preceding an expected stimulus. However, the anatomical origins of these predictions are unclear. Wang, Hagoort, and Jensen (2017) compared the processing of highly expected versus low expected words during sentence comprehension. They reported differential effects in the alpha (~10 Hz) and beta (~20 Hz) range involving a left frontal-temporal brain network with lower alpha and beta power in the high versus the low constraining conditions. In line with this, a large-scale language comprehension study (Schoffelen et al., 2017) reported prefrontal-to-temporal interactions, mainly peaking in the beta frequency channel. These studies support the role of beta activity in top-down generation of predictions, localizing it to a pre-frontal area, as would follow from classic models of language processing (Friederici, 2012; Hagoort, 2017; Lau, Phillips, & Poeppel, 2008). On the other hand, Piai, Roelofs, Rommers, and Maris (2015) localize predictive beta-band activity to motor cortex. They analyzed the oscillatory activity elicited by semantically highly-constraining versus low-constraining sentence contexts before processing of a target picture. Participants had either to perform a naming (production) or a judgment (comprehension) task. They observed similar beta desynchronization effects involving both left posterior temporal and motor regions, for both tasks, in the highly-constraining condition. The involvement of the motor system in prediction has indeed been put forward in different theoretical proposals (Dell & Chang, 2014; Federmeier, 2007; Molinaro, Monsalve, & Lizarazu, 2016; Pickering & Garrod, 2007, 2013).

For what concerns the oscillatory correlates of bottom-up information flow in language processing, experimental evidence seems at odds with what has been reported in the sensory processing literature. As discussed earlier, findings relating to gamma in the language literature typically show a positive relationship between power and predictability, congruent with Hermann et al.'s model (Hermann et al., 2004). In addition, the study by Wang et al. (2017) found post-stimulus gamma modulations related to prediction in the left pre-frontal cortex, rather than in perceptual (visual) regions. Furthermore, alpha activity in the temporal lobe