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When syntax meets action: Brain potential evidence of overlapping between language and motor sequencing

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ABSTRACT

This study aims to extend the embodied cognition approach to syntactic processing. The hypothesis is that the brain resources to plan and perform motor sequences are also involved in syntactic processing. To test this hypothesis, Event-Related brain Potentials (ERPs) were recorded while participants read sentences with embedded relative clauses, judging for their acceptability (half of the sentences contained a subject-verb morpho-syntactic disagreement). The sentences, previously divided into three segments, were self-administered segment-by-segment in two different sequential manners: linear or non-linear. Linear self-administration consisted of successively pressing three buttons with three consecutive fingers in the right hand, while non-linear self-administration implied the substitution of the finger in the middle position by the right foot. Our aim was to test whether syntactic processing could be affected by the manner the sentences were self-administered. Main results revealed that the ERPs LAN component vanished whereas the P600 component increased in response to incorrect verbs, for non-linear relative to linear self-administration. The LAN and P600 components reflect early and late syntactic processing, respectively. Our results convey evidence that language syntactic processing and performing non-linguistic motor sequences may share resources in the human brain.

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1. Introduction

There is a growing body of evidence in the literature emphasizing the relationship between language and sensorimotor processing in the so-called *embodied language* theoretical framework. This approach claims that sensorimotor simulation is at play during language processing and required for appropriate comprehension. From a neurobiological point of view, this notion implies that language comprehension relies at least partially on neural systems for perception and action (Barsalou, 2008; Fischer & Zwaan, 2008; Glenberg & Gallese, 2012; Pulvermuller, 2005; de Vega, Glenberg, & Graesser, 2008).

Evidence for this perspective has largely come from studies in which the motor activity associated with action language has been investigated with different methods, from behavioral measures to neuroimaging techniques. In a seminal paper, Glenberg and Kaschak (2002) reported that the processing time of action sentences was modulated by the preparation or internal simulation of an intended movement that either matched or mismatched the action described in the sentence. This experimental procedure is known as the *action-sentence compatibility effect* (ACE). In addition to these findings, a few electrophysiological studies have combined the ACE paradigm with the study of Event-Related brain Potentials (ERPs). For instance, Aravena et al. (2010) reported, on the one hand, that the incompatibility between a hand movement and the action depicted in a sentence significantly increases the N400 ERP component, a centro-parietal negativity reflecting semantic processing (Kutas & Federmeier, 2011). On the other hand, these authors showed a decrement in the ERP motor potential (MP) component associated with the hand movement, suggesting a bidirectional impact between language comprehension and motor processes. A similar pattern has also been found in studies of motor compatibility effects in language comprehension. Specifically, larger N400 amplitudes occur when participants read sentences referred to two simultaneous manual actions, which cannot be performed at once (Santana & de Vega, 2013). This type of data supports some common functional substrates for semantic processing of language and motor control.

Functional Magnetic Resonance Imaging (fMRI) studies, on the other hand, have reported activations of motor regions triggered by action language. For example, Pulvermüller and colleagues have described that understanding action verbs, in comparison with nouns referring to perceptual objects, elicited activations in fronto-central regions, including the premotor and motor cortex (Pulvermüller, 1996, 2005). Also, processing action verbs associated to different parts of the body elicited activations in somatotopic regions of the cortex that partially overlap with those specifically involved in the execution of those actions (Hauk & Pulvermüller, 2004; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005). In addition, somatotopy in response to sentences describing actions has also been reported, yielding a strong activation of the fronto-parietal-motor network when compared with more abstract content sentences (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; de Vega et al., 2014; Tettamanti et al., 2005).

Embodied language theories, however, go beyond primary sensorimotor information and assume that embodiment could also entail abstraction. Comprehending words draws on reusing the whole sensorimotor representations that provided the basis for the acquisition of the corresponding concepts. Thus, the reactivation of multimodal states integrates conceptual information into a general and abstract representation, which is a function of cortical association areas as those described in classical neuroanatomical models of semantic memory (Barsalou, 2008, 2016a, 2016b). These areas of heteromodal cortex, which include the inferior parietal lobe and much of the temporal lobe –among others-, play an important role in the supramodal representations that allow the manipulation of abstract knowledge in semantic processing, having been cited as semantic “hubs” or high-level “convergence zones” (Binder & Desai, 2011; Damasio, 1989; Kiefer & Pulvermüller, 2012).

Importantly, the claim that embodied language also comprises abstract knowledge actually implies that syntax may as well be accounted for by this perspective. Several authors have indeed addressed this issue. In this regard, Kreiner and Eviatar (2014) propose that syntax is an emergent linguistic abstraction that can be embodied by different prosodic patterns in different languages. For example, hierarchic relationships between elements would be an abstraction that may be coded by intonation and/or by pauses in different languages. In turn, Glenberg and Gallese (2012), in their theory of *action-based language* (ABL), link language and action through the neural overlap between mirror neuron system for action and Broca's area for speech articulation. In this frame, these authors propose that syntax emerges from action control. Put simply, as the basic function of motor control is to combine movements in a way that produces goal-directed action and the main function of syntax is to combine linguistic components to produce a communicative goal, then syntax emerges from reusing control of action to produce control of speech (Glenberg & Gallese, 2012). Indeed, the well-known fact that Broca's area is functionally involved both in the syntax and in the sensorimotor systems supports this view (Clerget, Winderickx, Fadiga, & Olivier, 2009; Friederici, Bahlmann, Friedrich, & Makuuchi, 2011; Moro, 2014; Pulvermüller & Fadiga, 2010). In a similar vein, and from a mechanistic point of view, syntactic links (including agreement and other non-local syntactic relationships), have been proposed to be neurobiologically grounded in *discrete combinatorial neuronal assemblies*, or DCNAs, that bind together pairs of constituents (Pulvermüller, 2010). These combinatorial emerging aggregates of sequence detectors (similar to those found in a range of animals), do provide a candidate neuronal mechanism of syntactic binding circuits in establishing grammatical relationships in sentences (Pulvermüller & Knoblauch, 2009).

To date, however, empirical research on embodied language has mainly focused on the semantic domain, i.e., on how processing the *meaning* of action words (nouns and verbs), either presented in isolation or embedded into sentences, recruits our sensorimotor systems. By contrast, the relationship between syntax and embodiment has scarcely been addressed. Ensuing theoretical proposals that link