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Subliminal display of action words interferes with motor planning: A combined EEG and kinematic study

Véronique Boulenger *, Beata Y. Silber, Alice C. Roy, Yves Paulignan, Marc Jeannerod, Tatjana A. Nazir *

L2C2-Institut des Sciences Cognitives, UMR 5230 CNRS/UCBL, 67 Boulevard Pinel, Université Claude Bernard Lyon I, 69675 Bron Cedex, France

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ABSTRACT

Recent evidence has shown that processing action-related language and motor action share common neural representations to a point that the two processes can interfere when performed concurrently. To support the assumption that language-induced motor activity contributes to action word understanding, the present study aimed at ruling out that this activity results from mental imagery of the movements depicted by the words. For this purpose, we examined cross-talk between action word processing and an arm reaching movement, using words that were presented too fast to be consciously perceived (subliminally). Encephalogram (EEG) and movement kinematics were recorded. EEG recordings of the "Readiness potential" ("RP", indicator of motor preparation) revealed that subliminal displays of action verbs during movement preparation reduced the RP and affected the subsequent reaching movement. The finding that motor processes were modulated by language processes despite the fact that words were not consciously perceived, suggests that cortical structures that serve the preparation and execution of motor actions are indeed part of the (action) language processing network.

1. Introduction

A recently emerging view considers that language processing and motor action share common neural substrates. Two major models, the first based on Hebbian learning (Pulvermüller, 1996, 2001, 2005) and the second on the existence of the "mirror neuron system" (Fadiga and Craighero, 2004; Gallese and Lakoff, 2005; Rizzolatti and Arbib, 1998; Rizzolatti et al., 2001), suggest that processing of action words relies on activation of the motor programs used to perform, observe or simulate the actions referred to by words, either because of correlation learning (Pulvermüller, 2005) or because of a predisposition for imitation learning (Rizzolatti and Arbib, 1998). Evidence for such shared representations between word processing and sensory-motor information is provided by a large range of empirical data (Aziz-Zadeh et al., 2006; Boulenger et al., 2006, 2008; Buccino et al., 2005; Glenberg and Kaschak, 2002; Glover et al., 2004; Hauk et al., 2004; Nazir et al., in press; Oliveri et al., 2004; Pulvermüller et al., 2005a,b; Tettamanti et al., 2005; Zwaan and Taylor, 2006; see Fischer and Zwaan, in press, for a recent review). fMRI Studies, for instance, have demonstrated somatotopic activation of motor and premotor cortices during processing of words or sentences referring to actions performed with arm, face or leg (Aziz-Zadeh et al., 2006; Hauk et al., 2004; Tettamanti et al., 2005). Transcranial magnetic stimulation (TMS) studies have also revealed that the left motor cortex excitability changes during processing of words or sentences denoting bodily actions (Buccino et al., 2005; Oliveri et al., 2004).

First attempts to identify the functional role of language-related activity in cortical motor regions have also been made by investigating the time course of this activity (Boulenger et al., 2006; Pulvermüller et al., 2005a). Using magnetoencephalography (MEG), Pulvermüller et al. (2005a) revealed a short-lived somatotopic activity in motor cortex while participants were listening to face- and leg-related action words. This activity was observed within 170–200 ms post word onset, which is the time-window within which early lexico-semantic effects typically occur (Hauk et al., 2006; Pulvermüller et al., 1999; Preissl et al., 1995; Sereno et al., 1998; Sereno and Rayner, 2003). Given this critical delay, the authors suggested that cortical motor regions could be involved in action word retrieval and may thus be essential to (action) language understanding (for a summary of this idea, see Pulvermüller, 2005). Boulenger et al. (2006) corroborated this finding by showing cross-talk between action word processing and overt motor performance within the same early time-window. Fine-grained analyses of movement kinematics could in fact reveal that relative to nouns without specific motor associations, processing action verbs altered the kinematics of arm reaching movements. When the two tasks were performed concurrently, processing of action verbs interfered with the movement (i.e., it delayed and decreased wrist cceleration peak within 200 ms following onset), whereas

* Corresponding authors.
E-mail addresses: boulenger@isc.cnrs.fr (V. Boulenger), nazir@isc.cnrs.fr (T.A. Nazir).

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facilitation of motor performance was observed when the words were processed prior to movement onset (i.e., it shortened time to wrist acceleration peak). By providing unambiguous evidence for the existence of behavioral correlates to language-related activity in motor regions, this latter study demonstrated that processing of action verbs and motor action share common neural representations to the point that the two processes can interfere with each other.

2. The present study

Despite these intriguing findings, a major argument against the assumption that cortical motor regions are involved in (action) word processing is that, even though language-induced activity in motor regions is observed within less than 200 ms after word onset, this activity could nonetheless result from mental motor imagery (voluntary or involuntary mental representation of the movements depicted by the words; see Jeannerod, 1994) that occurs after the word has been identified. If so, cortical motor regions would not be vital for the effective processing of action words and language-related cortical motor activity should rather be considered a by-product of language processing with no specific functional relevance. The aim of the present study is to rule out this possibility, by investigating cross-talk between language and motor processes using visual words that are masked by other visual symbols, and presented too fast to be consciously perceived: Words that are not consciously perceived can actually not trigger mental motor imagery.

Brain imaging studies have established that although participants do not consciously perceive a visually masked word, the subliminal stimulus automatically pre-activates essential parts of the cerebral networks for word processing (Dehaene et al., 2001) and boosts recognition when the same word is displayed again shortly afterwards (c.f. masked priming; Forster and Davis, 1984; Forster, 1999; also see Marcel, 1983). If cortical motor regions are essential to the processing of action-related language, masked words that describe motor actions should therefore activate cortical motor regions. A recent study that we conducted with patients suffering from Parkinson's disease (PD), a neurodegenerative disease primarily characterized by motor disorders, seemed to confirm this assumption (Boulenger et al., 2008). In this study, the subliminal display of a word (e.g., TABLE) was used to prime a target word (e.g., table) which was presented overtly shortly afterwards. PD patients were required to make a lexical decision to the overtly displayed target (i.e., deciding whether the stimulus was a word or not) and reaction time was measured. In such "masked priming" paradigms, reaction time is typically faster when prime and target are identical (TABLE–table; e.g., Ferrand et al., 1994), compared to a condition where prime and target are different (CVKLS-table). The results of this study revealed that the receptivity of PD patients for subliminal displays of visual words was conditional on word meaning. When PD patients were off dopaminergic treatment (i.e., when motor disorders were important), they showed a selective deficit to capture information from masked action verbs – but not from masked concrete nouns. That is, while there was little or no priming effect for verbs, strong priming was observed for nouns. Levodopa intake, which re-establishes normal activation level in premotor and motor areas via the striato-frontal loop, then restored the motor disorders as well as the selective deficit for action verbs. These results are thus among the first to directly show that the cortical motor system contributes to the effective processing of action-related language, because the selective deficit for verbs was contingent on the motor disorder. The present study aims at substantiating this finding by analyzing the impact of subliminal action word displays on the neurophysiological correlates of motor preparation (using electroencephalography, EEG) and on the subsequent execution of the movement (using kinematic analyses) in healthy participants.

2.1. Electrophysiological indicator of motor processing: the readiness potential

A major part of the motor program that controls movement is computed prior to movement onset and guarantees the efficient organization of the motor act (Requin et al., 1991; Riehle, 2005; Schmidt et al., 1979). A simple observation that highlights the role of these preparatory processes is that providing prior information about movement parameters (e.g., movement direction), or removing uncertainty about when a movement has to be executed, shortens considerably motor reaction time (Riehle, 2005). Given the significant role of preparatory processes for a movement, interferences between language and motor action as previously reported (Boulenger et al., 2006; Nazir et al., in press) should also be observed when action words are processed during motor preparation period. Since the "Readiness potential" (RP) is a well-known electrophysiological correlate of movement preparatory processes (Kornhuber and Deecke, 1965; for a review, see Colebatch, 2007), we aimed at analyzing this potential during language processing.

The RP, which is believed to arise from premotor and primary motor areas, is characterized by a slow negative going potential that starts approximately 1 s prior to movement onset, with maximum amplitudes at centro-lateral recording sites (Ball et al., 1999; Cunnington et al., 2003; Deecke and Kornhuber, 1978; Deecke et al., 1987; Praamstra et al., 1996; Shibasaki et al., 1980). The RP is generally elicited prior to self-paced voluntary movements, but it has also been recorded in relation to stimulus-triggered movements (Castro et al., 2005; Kilner et al., 2004). Moreover, some investigators have regarded the RP as equivalent to the late component of the contingent negative variation (CNV, which is a negative potential recorded prior to cued movements; Walter et al., 1964), in paradigms in which a "warning" stimulus (S1; which gives advanced information about the movement that has to be performed) precedes an "imperative" stimulus (S2) to which participants must react (S1–S2 paradigm; Grünewald et al., 1979; Rockstroh et al., 1982; Rohrbaugh et al., 1976; Rohrbaugh and Gaillard, 1983).

In the present study, we will use a S2-centered CNV-like paradigm in which subsequent to the presentation of a (visual) preparatory-signal (S1), participants have to quickly reach and grasp an object in response to a (visual) go-signal (S2). During the preparatory period (i.e., the time interval between S1 and S2), action verbs, concrete nouns or strings of consonants will be displayed subliminally on a screen. Using a novel paradigm that combines EEG with kinematic analyses, we will assess the influence of these subliminal displays on the concurrent preparation and subsequent execution of the reaching movement, by determining the impact of each stimulus category on the profile of the RP[1] and on kinematic parameters of motor performance.

3. Predictions

In line with our previous findings (Boulenger et al., 2006; Nazir et al., in press), we predict that subliminal displays of action verbs

[1] In agreement with previous studies (Castro et al., 2005; Kilner et al., 2004), we will use the term RP to denote the here observed movement-related potential. Actually, in our CNV-like paradigm, on appearance of the S1, participants had all necessary information to perform their movement. Since the CNV (also called "expectancy wave") requires that S1 only delivers partial information about the subsequent movement, that is, one must have a "state of uninformed waiting" during the interstimulus interval (Dimitrov, 2004), we decided not to consider the observed potential as a proper CNV but rather as a RP.