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Abstract and concrete phrases processing differentially modulates cortico-spinal excitability

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ABSTRACT

An important challenge of embodied theories is to explain the comprehension of abstract sentences. The aim of the present study was to scrutinize the role of the motor cortex in this process. We developed a new paradigm to study the abstract-concrete dimension by combining concrete (i.e., action-related) and abstract (i.e., non-action-related) verbs with nouns of graspable and non-graspable objects. Using these verb-noun combinations we performed a Transcranial Magnetic Stimulation (TMS) on the left primary motor cortex while participants performed a sentence sensibility task. Single-TMS pulses were delivered 250 ms after verb or noun presentation in each of four combinations of abstract and concrete verbs and nouns. To evaluate cortico-spinal excitability we registered the electromyographic activity of the right first dorsal interosseous muscle. As to verb-noun integration, analysis of motor evoked potentials (MEPs) after TMS pulse during noun presentation revealed greater peak-to-peak amplitude in phrases containing abstract rather than concrete verbs. Response times were also collected and showed that compatible (Concrete–Concrete and Abstract–Abstract) combinations were processed faster than mixed ones; moreover in combinations containing concrete verbs, participants were faster when the pulse was delivered on the first word (verb) than on the second one (noun). Results support previous findings showing early activation of hand-related areas after concrete verbs processing. The prolonged or delayed activation of the same areas by abstract verbs will be discussed in the framework of recent embodied theories based on multiple types of representation, particularly theories emphasizing the role of different acquisition mechanisms for concrete and abstract words (Borghi and Cimatti, 2009,2012).

1. Introduction

The ability to understand and use abstract words is an important part of the human capacity to interact with the environment and with others. While many studies have been devoted to this important topic, the issue of how abstract concepts and words are represented is still unsolved (for a recent review, see Pecher et al., 2011). It is well known that

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abstract words are remembered and recognized more slowly than concrete ones (Schwanenflugel, 1991). Their processing can engage mental imagery, but at a lower rate and with a greater variability compared to concrete words (Paivio et al., 1968; Paivio, 1991). It is also well established that abstract words are acquired later than concrete and generally highly imaginable words (Bird et al., 2001). Finally, the double dissociations found between the understanding of abstract and concrete words (Shallice and Warrington, 1975; Warrington, 1975) further suggest that, even if the domain of 'abstract concepts' is not homogeneous, there must be some common features that link its variegated members. In recent years many neuroimaging and meta-analyses have investigated the different neural correlates involved in abstract and concrete concepts (for a recent quantitative meta-analysis see Wang et al., 2010; see also Kiefer and Pulvermüller, 2012). In addition, several brain imaging studies have recently investigated the difference between figurative and literal actions (e.g., Aziz-Zadeh et al., 2006; Boulenger et al., 2009; Boulenger et al., 2012; Desai et al., 2011). For example, Boulenger et al. (2009) have shown that semantic somatotopy of the motor system characterizes not only literal but also sentences with a figurative meaning (e.g., "kick the ball" vs. "kick the habit"). Other studies suggest an involvement of both the sensory-motor system and the semantic one. For example, Desai et al. (2011) found with fMRI some similarities between abstract and metaphoric sentences in the activation of left superior temporal regions suggesting that the comprehension of abstract words as well as of action metaphors is based on both sensory-motor simulations and lexical-semantic codes.

On one hand the concern for the difference between abstract (and figurative) and concrete concepts is due to a genuine interest in the specific topic, on the other hand this interest is strongly related to the theoretical implications of this issue for embodied and grounded theories of cognition (for a review on different kinds of embodied views, see Goldman and De Vignemont, 2009). Embodied theories vary in their details, but most of them maintain that all concepts and words activate a simulation mechanism that recruits the same action, perception and emotional networks activated during actual experience with their referents (e.g., Barsalou, 1999, 2003; Glenberg and Robertson, 2000; Zwaan, 2004). Notice that different versions of the notion of simulation have been proposed (for reviews, see Borghi, 2012; Decety and Grezes, 2006). The term "simulation" as we intend it here involves two aspects: it implies the re-enactment of past experiences (Barsalou, 1999) and it is predictive. It refers to a process that is embodied, unconscious, not deliberate, and it is aimed at action preparation (Gallese, 2009). In contrast with other views (e.g., Decety and Ingvar, 1990) simulating does not imply a deliberate reactivation of previously performed actions, and it does not consist in a posteriori forms of motor imagery. Empirical evidence on simulation is compelling with respect to concrete concepts and words. For example, Pulvermüller et al. (2005a,b) found a specific and early (150 ms) facilitatory effect of TMS sub-threshold stimulation of the motor cortex on the action words processing. In their study, participants were presented with single words referring to leg (e.g., to kick) or hand–arm actions (e.g., to pick) and were asked to perform a lexical decision task. Leg words recognition was faster when TMS targeted the leg area than when TMS was delivered over upper limb representation; symmetrical results were obtained for hand–arm verbs. The results showed that the activation of motor and premotor areas modulates the processing of specific kinds of words, semantically related to the arm or the leg (see also Scorolli and Borghi, 2007; Scorolli et al., 2009).

Nevertheless the challenge embodied theories have to face with is to clarify whether abstract concepts and words are also represented via embodied simulations. Mental metaphors could represent a potential solution, as they import the image-schemas derived from the source domain of sensorimotor experience (Lakoff, 1987; Gibbs and Steen, 1999). Compelling evidence has been collected in favor of this approach (e.g., Casasanto, 2009), but it is hard to foresee how it can be generalized to all varieties of abstract words.

Recently, some scholars have addressed the issue by getting to the root of the problem: embodied accounts of language have focused largely on language grounded in bodily experiences but have neglected that language also plays a role in shaping our experience (Borghi and Cimatti, 2009, 2012; Borghi and Pecher, 2011). In their proposal (Words as Tools, WAT) Borghi and Cimatti (2009, 2012), similarly to other authors (Dove, 2009, 2011; Louwerse and Jeauniaux, 2009; Barsalou et al., 2008; Kiefer and Barsalou, 2011; Simmons et al., 2008), try to integrate linguistic and modal approaches. The unique quality of the WAT proposal maintains that the linguistic system does not simply involve a form of superficial processing and that words cannot be conceived of as mere signals of something. Words are also tools that allow us to operate in the world (Clark, 2007; Gianelli et al., 2012; Mirolli and Parisi, 2011; Tylèn et al., 2010). The WAT proposal has direct implications for the explanation of abstract word meanings. Indeed, Borghi and Cimatti (2009, 2012) proposed that, probably due to their different acquisition mechanisms, abstract word meanings rely more than concrete word ones on the social experience of language. With concrete words, such as "phone", the word's referent can be indicated and tagged using linguistic labels. With abstract words, instead, there is not a specific referent to be indicated. In this case, the word used by others, such as "freedom", plays a major role, as it helps assemble a set of diverse sensorimotor experiences (e.g., we put together different experiences of freedom once we have learned the word "freedom"). In addition, since there is no referent to indicate, in the case of abstract words the contribution of other members of the linguistic community becomes crucial, as they can provide useful explanations of the word meaning. For example, as argued by Prinz (2002), to learn the word "democracy" we may visualize a series of scenes, but also rely on the opinion of authoritative members of our community. In support of this proposal, Borghi et al. (2011) have shown that the acquisition modality of novel concrete and abstract words (manipulation of their referents vs. simply visualization of scenes with interacting objects) has an impact on their representation: in a verification task participants responded faster to abstract words when using the microphone, and to concrete words when using the keyboard. The results indicate that concrete words evoke more manual