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Abstract semantics in the motor system? – An event-related fMRI study on passive reading of semantic word categories carrying abstract emotional and mental meaning

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ABSTRACT

Previous research showed that modality-preferential sensorimotor areas are relevant for processing concrete words used to speak about actions. However, whether modality-preferential areas also play a role for abstract words is still under debate. Whereas recent functional magnetic resonance imaging (fMRI) studies suggest an involvement of motor cortex in processing the meaning of abstract emotion words as, for example, 'love', other non-emotional abstract words, in particular 'mental words', such as 'thought' or 'logic', are believed to engage 'amodal' semantic systems only. In the present event-related fMRI experiment, subjects passively read abstract emotional and mental nouns along with concrete action related words. Contrary to expectation, the results indicate a specific involvement of face motor areas in the processing of mental nouns, resembling that seen for face related action words. This result was confirmed when subject-specific regions of interest (ROIs) defined by motor localizers were used. We conclude that a role of motor systems in semantic processing is not restricted to concrete words but extends to at least some abstract mental symbols previously thought to be entirely 'disembodied' and divorced from semantically related sensorimotor processing. Implications for neurocognitive theories of semantics and clinical applications will be highlighted, paying specific attention to the role of brain activations as indexes of cognitive processes and their relationships to 'causal' studies addressing lesion and transcranial magnetic stimulation (TMS) effects. Possible implications for clinical practice, in particular speech language therapy, are discussed in closing.

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1. Introduction

Whether sensorimotor areas of the brain are involved and functionally relevant for the processing and representation of meaning and concepts has driven an intensive debate between proponents of classical amodal symbolic system approaches (Anderson, 1983; Ellis & Young, 1988), as well as neurobiologically motivated models that incorporate semantic grounding or 'embodiment' (Barsalou, 1999, 2008; Glenberg & Gallese, 2012; Pulvermüller, 1999, 2005). While the former assume semantics to be represented in an amodal format, detached and independent from basal sensorimotor neural systems and therefore in *multi*-modal cortical areas alone, the latter postulate that semantic processes are carried by neuronal circuits distributed across multimodal areas, but also reaching into sensorimotor cortex. The theoretical explanation for such distributed semantic circuits comes from neurobiological theory, especially from structural cortical connectivity and functional correlational, Hebbian and anti-Hebbian learning mechanisms (Garagnani & Pulvermüller, 2016; Hebb, 1949). Accordingly, grounded semantic circuits form as a consequence of correlated neuronal activity driven by co-occurring words and referential semantic information present in the non-linguistic environment; only after such semantic grounding of a base vocabulary, indirect ('parasitic') semantic learning can be accomplished in linguistic contexts when novel words co-occur with already semantically grounded ones (Cangelosi, Greco, & Harnad, 2002). Because semantic grounding links symbols to action and perception information, it needs to involve neurons in modality preferential sensory and motor brain systems. The distributed neuronal circuits joining together word form and semantic information are flexible insofar as their context-induced priming and task-induced preactivation of cortical areas influences their activation signatures (Grisoni, Dreyer, & Pulvermüller, 2016; Pulvermüller 2013a and 2018).

In essence, the two proposals under discussion imply either the exclusive relevance of multimodal (or sometimes inappropriately dubbed 'amodal') cortical areas for semantic processing, or rather the relevance of semantic circuits that draw upon these same areas and, in addition, reach into modality preferential sensory and motor areas. In the debate about embodied cognition and action semantics, an extreme position that motor or sensory cortex are the only sites carrying meaning has been aired. However, such an extreme view has, as to the best of our knowledge, exclusively been described as a straw man in critical statements on embodiment (e.g., Mahon & Caramazza, 2008). Researchers noting the importance of grounding in semantic processing consider this straw man position as a case of 'misembodiment' (Pulvermüller, 2013b) and as a 'Quixotic' theoretical dead end (Barsalou, 2016). We will therefore ignore this unrealistic view here and take it for granted that concepts and words tend to activate multimodal areas in frontal, temporal and parietal association cortices (Binder & Desai, 2011; Binder, Desai, Graves, & Conant, 2009; Pulvermüller, Kherif, Hauk, Mohr, & Nimmo-Smith, 2009).

At this stage, the most critical question is whether modality-preferential sensorimotor areas make additional contributions to semantic processing and representation. Lesion studies and work investigating the causal influence of local cortical activity changes might be seen as most appropriate for addressing this issue. However, as we discuss below, in the recent history of cognitive neuroscience, important clues came from neuroimaging experiments looking at brain activity to linguistic stimuli with different meanings. Together, the correlational (imaging) and causal (lesion or neurostimulation) studies can provide a good picture of the role of cortical areas in semantic processing. This question is not only of relevance in the context of general theories of language comprehension, but also for clinical applications, like aphasia therapy. Here, traditional approaches that apply for example confrontation naming (e.g., Howard, Patterson, Franklin, Orchard-Lisle, & Morton, 1985), focus predominantly on word and language training in isolation, as it would be sufficient following the implications of aforementioned amodal symbolic system theories. In contrast, alternative therapeutic approaches, like constraint induced aphasia therapy (CIAT, Pulvermüller et al., 2001) and intensive language action therapy (ILAT, Difrancesco, Pulvermüller, & Mohr, 2012), also consider an involvement of action related brain areas in language comprehension and especially stress the importance of an action-embedded context for language training.

1.1. *Brain correlates of semantic grounding of concrete semantics*

From a neuroscientific perspective, a range of results confirmed the involvement of sensorimotor areas in, and even their relevance for, semantic processing. For example, words used to speak about objects characterized primarily by visual, olfactory, gustatory and auditory information specifically activated the corresponding sensory areas (e.g., Barrós-Loscertales et al., 2012; González et al., 2006; Kiefer, Sim, Herrnberger, Grothe, & Hoenig, 2008). In the domain of action semantics, primary- and pre-motor areas were shown to become active and to index the body part with which the action denoted by an action verb is typically executed, as well as the body movements afforded by objects such as tools or food items (e.g., Carota, Moseley, & Pulvermüller, 2012; Hauk, Johnsrude, & Pulvermüller, 2004; Martin, Wiggs, Ungerleider, & Haxby, 1996). Further research showed that sensorimotor activations reflecting semantic aspects of symbols occur even when subjects do not attend to the incoming symbols, thus demonstrating a degree of automaticity of semantic activations (Pulvermüller, Shtyrov, & Ilmoniemi, 2005; Shtyrov, Butorina, Nikolaeva, & Stroganova, 2014). In addition, the early emergence of these sensorimotor activations, which are as early as the earliest semantic brain indexes known to date (ca. 100–200 msec), suggest their semantic status and make it unlikely that they resemble epiphenomenal post comprehension processes. Furthermore, behavioral paradigms (Connell, Lynott, & Dreyer, 2012; Shebani & Pulvermüller, 2013; Witt, Kemmerer, Linkenauger, & Culham, 2010), neurostimulation approaches (Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005; Willems, Labruna, D'Esposito, Ivry, & Casasanto, 2011), as well as studies in neurological patients