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Early lexico-semantic modulation of motor related areas during action and non-action verb processing

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ABSTRACT

Although action verb processing deficits have been described in diseases affecting the motor system, research on temporal processing in this area has not been reported. In this study, action and non-action verb processing was contrasted in healthy volunteers using electro-encephalography. These data may serve as a control condition for further research in motor disorders. Latency and amplitude evaluations as well as source reconstruction were applied on event-related potentials. Action verbs evoked higher activation in bilateral sensorimotor areas from 155 to 174 ms and in bilateral dorsolateral prefrontal cortex (DLPFC) from 219 to 238 ms. Hand action verb processing activates the motor programmes of the actions the verbs refer to. This seems not restricted

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to the core (pre)motor cortical areas of the brain. A broad motor brain network is hypothesized to be involved. While sensorimotor activation seems essential for action verb understanding, this cannot be concluded for DLPFC activation.

1. Introduction

Substantial research has been conducted on the perception of action related linguistic material such as action verbs. Besides the classic language areas, also the premotor and primary motor cortex are reported to be involved in the processing of action-related words and sentences. Moreover, this processing appears to occur in a somatotopic way. Action verbs related to face, arm or leg movements elicit the strongest activation close to the cortical motor representation of the face, hands or legs respectively (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Boulenger, Hauk, & Pulvermüller, 2009; Buccino et al., 2005; Hauk, Johnsrude, & Pulvermüller, 2004; Kemmerer, Castillo, Talavage, Patterson, & Wiley, 2008; Pulvermüller, Härle, & Hummel, 2001; Pulvermüller, Shtyrov, & Imoniemi, 2005; Raposo, Moss, Stamatakis, & Tyler, 2009; Repetto, Colombo, Cipresso, & Giuseppe, 2013; Shtyrov, Hauk, & Pulvermüller, 2004; Tettamanti et al., 2005). Although this somatotopical activation is not always found (Arévalo, Baldo, & Dronkers, 2012; Postle, Ashton, McFarland, & de Zubicaray, 2013), a review by Kemmerer and Gonzalez-Castillo (2010) showed surprising consistencies among different labs and languages.

Unfortunately, the underlying mechanism responsible for the motor activation remains a contentious issue because conflicting results are found on the processing stage during which this motor activation occurs. Some studies revealed somatotopic motor activation after auditory and visual single word presentation from 130 to 170 ms (Pulvermüller et al., 2005; Shtyrov et al., 2004) and 210 to 230 ms (Hauk & Pulvermüller, 2004b) respectively. In addition, visually presented action words appear to interfere with a reaching movement already within 200 ms after word onset (Boulenger et al., 2006). Within the first 200 to 250 ms after word presentation, essential lexical and semantic processes are known to occur (Federmeier & Kutas, 2001; Hauk, Coutout, Holden, & Chen, 2012; Penolazzi, Hauk, & Pulvermüller, 2007). Thus, actions and action semantics related to words apparently share cognitive and neural resources. This is in line with theories of embodied cognition which state that all concepts are (partly) modality dependent and are grounded in neural action and perception systems (e.g. Barsalou, 1999; Dove, 2009). Consequently, motor areas are suggested to be involved in lexical access (Hauk, Shtyrov, & Pulvermüller, 2008). By contrast, other studies found a much later motor cortex modulation around 500 ms post-stimulus onset (Oliveri et al., 2004; Papeo, Vallesi, Isaja, & Rumiati, 2009). At this stage, post conceptual processes of word recognition occur (Marinkovic et al., 2003). Motor strip activation would then follow the identification of the action concept, instead of being part of it. This 'spreading activation' occurs because the word's concept is associated with the motor system controlling the respective action (Hickok, 2010) or because of mental imagery (Tomasino, Fink, Sparing, Dafotakis, & Weiss, 2008).

A recent study conducted by Moseley, Pulvermüller, and Shtyrov (2013) used excellent equipment to elucidate which processing stage is involved. Passive reading of written words was found to evoke maximal brain responses at 150 ms post-stimulus onset. Besides widespread activity in perisylvian regions for all words, inferior frontal gyrus and precentral cortex were significantly more engaged during action compared to abstract word processing. Thus, category-specific semantics seem to be represented in the neural systems for perception and action. As these regions were activated within the first 200 ms, this representation seems essential for concept understanding. Unfortunately, while the action words were mostly verbs, the abstract words were a conglomeration of both nouns and verbs. Although grammatical class in itself does not have an influence on the organization of knowledge in the brain (Vigliocco, Vinson, Druks, Barber, & Cappa, 2011), neurophysiological differences between verbs and nouns have been reported (Kellenbach, Wijers, Hovius, Mulder, & Mulder, 2002; Osterhout, Bersick, & McKinnon, 1997). Thus, a possible lexical/grammatical confound cannot be excluded to have influenced the results.