How Tapping Affects Talking: Reversals of Action-language Interaction Effects

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Abstract

A growing body of research shows that there is a close functional connection between motor and language systems of the human brain. Behavioural and TMS investigations document a causal influence between language and motor systems, an influence that is bidirectional and which can be facilitatory or inhibitory. While it is still not fully clear what determines the sign of the interaction effect (inhibition or facilitation) between action and language, some factors have shown to have an influence on the sign of the effect. A few studies have even managed to successfully reverse the sign of the effect between language and motor processes. This paper provides a short review of these reversals of action-language effects and discusses how this flexibility of motor-language interaction may be explained.

Keywords: Action-language interaction, Motor movement, Action word, Semantics, Working memory

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Introduction

A great deal of interest and debate has recently revolved around the interaction of language and action systems of the brain. Numerous behavioural and transcranial magnetic stimulation (TMS) investigations have examined the effect of motor systems activity on the processing of action-related language as well as effects in the reverse direction, from language processes on motor performance. Findings from these studies demonstrate that motor systems activity modulates the processing of action-related language (e.g., D'Ausilio et al., 2009; Glenberg & Kaschak, 2002; Glenberg et al., 2008; Repetto et al., 2013; Shebani & Pulvermüller, 2013, 2018; Willems et al., 2011) and that action language processing affects motor behaviour or excitability (Boulenger et al., 2006; Buccino et al., 2005; Dalla Volta et al., 2009; de Vega et al., 2013; Fadiga et al., 2002; Gianelli & Dalla Volta, 2015; Liepelt et al., 2012; Sato et al., 2008). Some of these investigations document a negative and inhibitory causal influence between language and motor function, while others show a positive and facilitatory effect. TMS and action interference experiments focussing on body-part specific action words (i.e. words referring to actions performed with either the arms or legs such as *grasp* and *kick*) have demonstrated a functional connection between these subtypes of action words and their corresponding arm or leg representation of the motor cortex (for example see, Gianelli & Dalla Volta, 2015; Mirabella et al., 2012; Pulvermüller et al., 2005; Repetto et al., 2013; Shebani & Pulvermüller, 2013; Vukovik et al., 2017; Willems et al., 2011). These results suggest a close, functionally specific and sophisticated link between language and cortical motor systems that is dependent on the meaning of action-related language. Alternatives to this embodied approach downplay these causal effects, highlighting the role of amodal conceptual representations (see Mahon & Hickok, 2016). However, the idea of such amodal conceptual hubs is not incompatible with a meaning dependent role of sensorimotor systems in language processing, as mentioned in previous studies (Pulvermüller et al., 2010; Pulvermüller et al., 2014; Shebani et al., 2017).

The fact that some studies found inhibition effects while others found facilitation effects raises the question of what factors determine the sign of the causal influence between motor and language processes and whether the sign of the interaction effect can be reversed. Recently, a few studies looking at action-language effects have found that the sign can be reversed. This paper reviews these studies and briefly discusses these flexibility effects.

A matter of linguistic task?

A number of factors appear to determine whether the sign of action-language interaction is facilitatory or inhibitory. Some authors have suggested that the sign of the interaction between action-related language and motor responses depends on the type of linguistic task used (Mirabella et al., 2012). In a semantic task, they found an interference effect when subjects performed a reaching movement with their hand in response to arm-related action words, but when the same task was performed using non-linguistic cues, the interference effect diminished. Mirabella and colleagues point out that, in previous experiments, tasks involving understanding the meaning of an action word or semantically processing an action-related sentence lead to interference effects, whereas lexical tasks not requiring semantic judgements did not (e.g., Buccino et al., 2005; Sato et al., 2008). However, the choice of linguistic task (semantic vs. non-semantic) as a key determiner of the sign of the effect does not account for some results which found facilitation effects even in tasks requiring semantic processing (Kaschak et al., 2005; Pulvermüller et al., 2005). For example, in examining the effect of movement perception on the processing of movement sentences, Kaschak et al. (2005) found interference effects in a non-semantic language task as well as in a semantic judgement task. They found that shared content between motion sentences and movement perception lead to slower responses and concluded that the sign of the effect depends on the integratibility of action language content and movement perception.

A matter of timing

Boulenger and colleagues were the first to examine whether the temporal relationship between motor and linguistic processes influences the sign of action language effects (2006). They measured arm movement kinematics of a grasping action while subjects performed a language task and found that when action words were processed prior to the onset of the action, it facilitated the grasping movement. On the other hand, when action words were processed during the execution of the grasping movement, it interfered with it. Manipulating the timing of action word presentation in relation to the grasping movement lead to a complete reversal of the sign of the effect from facilitation to inhibition. A study involving the processing of transfer sentences found similar results (de Vega et al., 2013). Subjects read sentences describing towards or away actions and performed a motor movement either towards or way from themselves to press a button. The motor movement either matched or mismatched the direction of the transfer. Results showed that, for matching conditions, when there was a shorter interval between action language processing and the cue for motor movement (SOAs 100 and 200ms), it slowed the motor response. However, with a longer interval (SOA 350ms) between the two tasks, motor movement was facilitated. As the same verbal stimuli and task demands were involved and only the temporal overlapping of semantic language processing and action was manipulated, this result suggests that it is the timing of action-language interaction that determined the sign of the causal effect.

The reversal of the pattern of interaction as a function of the temporal relation between motor and language tasks in de Vega et al. (2013) parallels the results reported in Boulenger et al. (2006). In both studies, priming of motor movement occurred when there was a longer interval between language and motor tasks, while interference occurred when the two tasks were performed concurrently or within a short interval of each other. Their results demonstrate that action word processing can assist or interfere with motor behaviour depending on relative timing of motor and language processes.

A matter of movement type

A recent study by Shebani and Pulvermüller (2018) investigated the possibility that the type of motor movement influences the sign of the interaction effect. In an earlier experiment by the same authors (Shebani & Pulvermüller, 2013), subjects were required to keep short lists of arm- and leg-related action words in working memory while performing complex, sequential movements with their hands and feet. Subjects had to perform a motor sequence known as a drumming exercise called the single paradiddle (RLRRLRLL, etc.). This already difficult motor task was made additionally challenging by requiring subjects to tap the pattern at their "frequency limit", or the highest beat frequency they could maintain without making errors. This complex and demanding motor task performed in conjunction with the action word memory task lead to an impairment of working memory for concordant arm- and leg-related action words; Subjects made more errors on arm-related word when performing the complex motor movements with their hands and more errors on leg-related words when performing the movements with their feet. The results demonstrate that motor systems of the brain can exert an inhibitory effect on action word memory.

The impairment of action word memory as a result of complex motor movement in Shebani and Pulvermüller (2013) lead to the question of whether motor systems can also have a facilitatory effect on action word memory if changes were made to the type of motor movement. Using the same working memory paradigm as in Shebani and Pulvermüller (2013), the authors carried out the same experiment but with a different motor task this time: simple finger alterations (Shebani & Pulvermüller, 2018). Instead of a complex drumming exercise, subjects were required to simply tap their fingers or tap their feet while keeping the lists of action words in memory. Interestingly, changing the motor sequence from a complex and demanding one to a very simple one resulted in a reversal of the interaction effect for arm-related action words. Instead of interfering with action word processing, the simple finger tapping assisted memory for arm-related words and subjects made relatively fewer errors on arm words when performing the simple repetitive movement with their hands. This enhancement of arm word memory as a result of simple finger alterations demonstrates that the sign of the functional interaction between language and motor systems can be altered by changing movement type. A similar enhancement of leg word memory as a result of foot tapping was not found in the study, possibly due to the foot movements used in the experiment being too similar to walking, a highly automatized motor activity that may require little cortical activity.

To further scrutinize these reversal effects, Shebani and Pulvermüller (2018) compared the results of the two experiments (complex vs. simple movements). A 2 x 2 x 2 ANOVA with the factors Word Category, Motor Movement and Task Complexity revealed a significant three-way interaction effect, indicating the reversal of the effect of motor movement on arm word memory when simple finger tapping was performed instead of the complex motor sequence. Further inter-experimental analyses reported in Shebani and Pulvermüller (2018) confirmed this finding. Focussing on the hand movement conditions of both experiments, analyses showed a significant cross-over Word Category x Task Complexity interaction, a significant word category difference in the simple motor task and a near significant difference in the complex motor task. A similar interaction was not found in an analysis of only the foot movement conditions (see Figure 1).

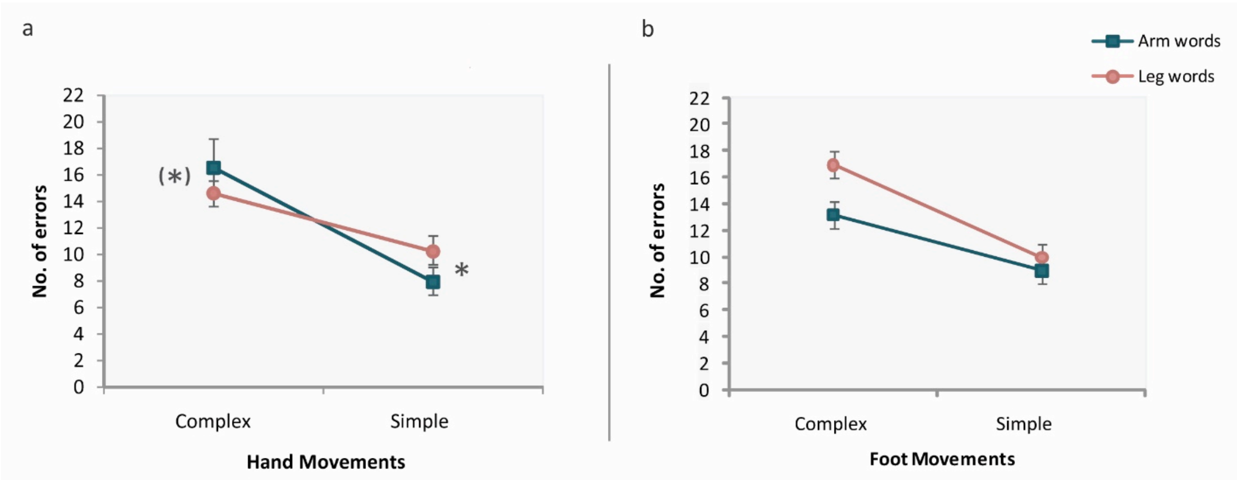

Figure 1: (a) Cross-over word category x task complexity interaction in the hand movement conditions. (b) word category x task complexity interaction in the foot movement conditions. From Shebani and Pulvermüller (2018, their figure 3).

A final inter-experimental analysis with the factors Motor Movement and Task Complexity on data from both hand and foot movement conditions for only arm-related words also revealed a significant interaction effect. As documented by these statistically significant interactions and word category differences, their results show that simple finger tapping enhanced working memory for arm-related words. As the two experiments used the same paradigm and word stimuli, changing only the motor task, the results and analyses in Shebani and Pulvermüller (2018) provide clear evidence that changing the complexity of motor movement can reverse the sign of the effect of motor movement on action word memory from inhibition to facilitation.

Discussion

While different features have been attributed to the reversal of the sign in studies of action-language interaction, there is some similarity in the explanations provided regarding the effects observed. In both studies that found relative timing of language-motor processes to alter the sign of the effect (Boulenger et al., 2006; de Vega et al., 2013), the authors concluded that the interference effects may be a result of competition between motor movement and action language processing for common neural resources, since both motor and language tasks were performed concurrently (Boulenger et al., 2006) or within very close temporal range of each other (de Vega et al., 2013). The impairment of arm- and leg-word memory as a result of complex motor movement described in Shebani and Pulvermüller (2013) also fits with this interpretation. Based on the semantic somatotopy model (Pulvermüller, 2001, 2005) which sees motor systems and language as sharing overlapping neuronal representations, Shebani and Pulvermüller (2013) explain that, as retaining lists of action words in memory and performing a complex motor sequence are two demanding tasks involving motor schemes that are incompatible with each other, competition for common processing resources results in local inhibition between overlapping and adjacent memory and motor circuits and, thus, interference effects. The interference effect of movement perception on motion sentence processing observed in Kaschak et al. (2005) is also explained along similar lines. Kaschak and colleagues interpret their finding as both tasks drawing on the same processing mechanisms, resulting in comprehension difficulty and the slower responses found.

With regards to facilitation effects, on the other hand, one explanation put forth relates to motor resonance and simulation. According to de Vega et al. (2013), two types of resonance phenomena may exist, an early onset and fast-fading motor resonance that causes interference, and a sentence-level motor resonance that is longer lasting and leads to facilitation. de Vega and colleagues posit that when there is a longer interval between action word processing and motor movement, early onset motor resonance related to processing the action-related language would have subsided by the time motor movement was executed, thereby, not causing any competition and, thus, interference between motor and language tasks. However, a longer lasting resonance may prime the subsequent motor movement leading to facilitation effects, as observed in their experiment when there was a longer interval between motor movement and action language processing. While the motor resonance hypothesis can account for results manipulating the timing of motor and language tasks, it does not explain reversals of the interaction effect when other features, such as movement type, are manipulated.

In Shebani and Pulvermüller (2018), an explanation for the complete reversal of the sign from interference to facilitation is given based on the semantic somatotopy model (Pulvermüller, 2001, 2005). According to this framework, if one motor programme fits into and forms part of a more complex motor programme, then the activation of the simpler motor programme may also co-activate the more complex one to a degree. The slight activation of the more complex motor programme may result in priming effects. As explained in Shebani and Pulvermüller (2018), the facilitation effects observed when simple motor movements were combined with action word memory may have arisen from the simple finger tapping pre-activating memory circuits within the motor network, thereby, facilitating memory for action-related words. As mentioned in Shebani and Pulvermüller (2018), this explanation can also account for the results of studies manipulating the temporal relation between motor and linguistic tasks. In both Boulenger et al. (2006) and de Vega et al. (2013), the facilitation effects found may have been due to the pre-activation of relevant motor circuits by the action language stimuli preceding the motor movement. This activation may have primed the reaching movement, leading to the faster motor responses reported in both studies.

Conclusion

Different features have been suggested as having an influence on whether action-language interactions lead to facilitation or inhibition effects. Factors shown to reverse the sign of the interaction effect include relative timing of motor and linguistic processes and the type of motor movement (simple vs. complex) performed in conjunction with action language processing. Explanations put forth for these flexibility effects have been briefly discussed. Future research may further explain the flexibility of the interaction between action and language and uncover additional features that can lead to reversals of language-interaction effects.

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