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Effects of language processing on spontaneous muscle activity

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There is evidence of the crucial involvement of the motor system in language understanding and production. We tested whether reading verbs that symbolized various actions would lead to an effector-specific modulation in subliminal muscle activity. Participants were lying in a relaxed position, and read a sequence of verbs while surface EMG was recorded of two upper body muscles (deltoideus and biceps brachii) and two lower body muscles (tibialis anterior and vastus medialis). The semantic category of the words had little effect on spontaneous muscle activity. The results are discussed in terms of shared neural circuits related to motoric and linguistic processing.

1. Introduction

The embodied cognition hypothesis states that cognition is grounded (embodied) in sensory and motor modalities (e.g., Niedenthal, 2007). Embodiment theories claim that cognition (in all its guises) is distributed across brain, body, and environment, and emphasize the causal role motor processes play in information processing, such as in mental arithmetic (e.g., Carlson, Avraamides, Cary, & Strasberg, 2007), language comprehension (Fischer & Zwaan, 2008; Glenberg & Kaschak, 2002), language production (Hirschfeld & Zwitserlood, 2012), and evaluative judgments (Dru & Cretenet, 2008; Eder & Klauer, 2009).

With respect to the processing of verbal material, there is evidence from brain imaging studies that verbs can activate neural structures related to motor control. Hauk, Johnsrude, and Pulvermüller (2004) performed an event-related functional magnetic resonance imaging (fMRI) experiment

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whereby subjects read a sequence of action words, such as ‘kick’ and ‘lick’. As expected, passively reading these words led to activation in left inferior temporal cortex, which is known to be involved in semantic processing. Importantly, there was also activation in the motor strip (motor and premotor cortex). Moreover, the pattern of activation occurred in a somatotopic fashion, i.e., the same structures were activated when participants generated the actual movements corresponding to the verbs presented.

Comparable findings were reported by Pulvermüller, Härle, and Hummel (2001) using event-related surface EEG. In that experiment subjects read three types of German action verbs; arm-related, face-related and leg-related words. Using current source density (CSD) maps it was found that action verbs elicited differential activation along the motor strip, such that the topography of activation corresponded to the well-known homuncular organization of the motor cortex.

Furthermore, an fMRI study by Aziz-Zadeh, Wilson, Rizzolatti, and Iacoboni (2006) revealed that the same fronto-parietal circuit was activated when subjects were watching action sequences and when they were reading verbal descriptions of these same actions. It was hypothesized that this effect could be mediated by a system of mirror neurons that re-enact the sensory and motor experiences during conceptual processing. The results suggested that “embodied representations” of language concepts are critically involved in action understanding. According to some authors (e.g., Tomasino, Weiss, & Fink, 2010) these results are suggestive of a process of perceptual and motor simulations that occur during language comprehension. In a similar vein, Pulvermüller (2012) emphasized the intimate link between language and the motor cortex, and he argued that language is “woven into action” (p. 452).

Motor representations may even play a causal role in language processing, as evidenced by motor pathologies. Individuals with motor neurone disease (MND) were tested by Bak and Hodges (2004) and it was found that their patients had subtle difficulties in action understanding. More specifically, one patient displayed – over the course of his disease – a gradual decrease in naming ability, but naming of nouns was less impaired than naming of verbs. Similarly, using a primed lexical decision task it was found that patients with Parkinson’s Disease (PD) had delayed responding to verbs, but not to other verbal material (Boulenger et al., 2008). Recently it was also found that individuals with PD who were off medication had a selective deficit in naming pictures that had a high degree of motor content (Herrera & Cuetos, 2012). These studies all show that movement disorders can affect language processing in a highly specific, action-related manner.

Relatively little is known about whether language processing also modulates muscle activity. Some studies have found that emotion words activated facial muscles. In one experiment (Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009) participants viewed words related to various emotion concepts, e.g., ‘cuddle’ and ‘murder’. Electromyographic (EMG) activity of four facial muscles was recorded. One group of participants was asked to explicitly focus on the emotional content of the words, whereas a control group was asked to indicate the typeface of the words. The first group, but not the second, displayed spontaneously elevated activity in facial muscles, specific to the emotion in question. For example, the zygomaticus muscle became more active during words related to joy, whereas the levator muscle became more active during words related to disgust. Furthermore, when facial responses were blocked, due to a pen that had to be clenched between lips and teeth, participants became less accurate in an emotion judgment task. This study thus revealed spontaneous elevation of resting state EMG to emotion words, but only when the words were consciously attended to.

A similar effect was found by Bayer, Sommer, and Schacht (2010). In that study participants were asked to make semantic decisions to affective target words embedded in sentences. Although the focus of that study was on event-related brain potentials, the authors also found an increase in the activity of corrugator muscle in response to negative words.

However, it is unknown to what extent the motor periphery is involved in language processing and whether processing of action-related verbs leads to an effector-specific increase in muscle activity. We conducted a study whereby we examined subliminal changes in muscle activity in the arms and legs, upon reading arm- and leg-related verbs. If semantic processing of action verbs leads to a process of mental simulation of the activities which, in turn, ‘spills over’ to the motor periphery, we expect to see changes in resting EMG activity that is specific to verb type. If, on the other hand, no changes in EMG activity are found, this then suggest that effects of embodied semantics are confined to the cortex and do not involve the effectors.

2. Methods

2.1. Subjects

Data were collected and analyzed from 12 healthy participants (3 male; 9 female), with a mean age of 25 years. They were all Dutch native speakers. All subjects gave written informed consent to participate, with ethical approval given by the local ethics committee at the Faculty of Human Movement Sciences of Amsterdam.

2.2. Material

Surface EMG data were collected using a Porti sytem (TMS International BV, Enschede, The Netherlands). Bipolar electrodes (Ag/AgCl, inter-electrode distance 20 mm) were placed on the muscle bellies of the following muscles: two muscles from the arms and upper body (deltoideus and biceps brachii) and two from the legs and lower body (tibialis anterior and vastus medialis; all right side). A grounding electrode was attached to the right patella. The recording sites were shaved when necessary and cleansed with alcohol. EMG data were recorded at 1 KHz and online filtered using a bandpass filter at 5 and 500 Hz. Data recording was synchronized with stimulus presentation using a trigger signal.

Each participant lay supine on a massage table in a relaxed position, with the headrest raised to an angle of 40° to permit viewing of the monitor, which was positioned in front of the subjects' feet. The distance between the monitor and the head was approximately 2 m. The stimuli consisted of Dutch verbs, presented in a clear white full screen font against a black background, and were thus clearly visible.

The stimuli consisted of the Dutch equivalent of three categories of verbs; (1) 18 arm verbs, which denote activities typically executed with the arm and upper body, such as 'reach', 'throw', 'catch', (2) 18 leg verbs, which denote activities typically executed with the leg and lower body, such as 'kneel', 'walk', and 'skate', and (3) 18 abstract verbs, which denote activities that are not typically associated with a body part, such as 'prove', 'convince', and 'hate'.

2.3. Procedure

The verbs were randomly presented in a consecutive fashion for 3 s each, always followed by a 3 s black screen. Participants were instructed to lay motionless and relaxed and not to move their limbs while watching the stimuli presented on the screen. As in the study of Niedenthal et al. (2009), we directly contrasted semantic processing and superficial processing of the verbs. There were three instructions for each participant. In one condition participants had to read each word and detect whether the letter 'R' was present in that word. When present they had to say 'yes', and when absent they had to say 'no'. This condition involves superficial processing of the words, and is referred to here as 'low attention'. In the second condition participants had to pay attention to the presence of arm-related words; when an arm-verb was displayed they had to say 'yes', and when another type of verb (leg or abstract) was displayed they had to say 'no'. In the third condition participants had to pay attention to the presence of leg-related words; when a leg-verb was displayed they had to say 'yes', and when another type of verb (arm or abstract) they had to say 'no'. These latter two conditions collectively involve deep processing of the words presented, because the semantic category of each word needs to be determined. In each of these three conditions the same set of 54 words was presented in a random order. The order of the conditions was also randomized across participants. No emphasis on speed was placed. The experimenter monitored the verbal responses. Although not recorded, errors were very rare as the task was easy and the action words had been selected a priori because of their distinctive semantic categories.

2.4. Data analysis

Data were analyzed as follows. We first removed the 50 Hz component from the EMG traces. Next, the EMG signal was rectified and low-pass filtered at 1 Hz. We determined for each muscle for each word for each condition the average EMG value. This was done on two time scales: short (0–500 ms) and long (0–3000 ms), because we did not know a priori how long putative effects of the verbal material would be present in the signal.

Statistical analysis was done using two complementary analyses. One analysis focused on possible effects of semantics within each muscle; to this end, for each of the 4 muscles (deltoideus, biceps brachii, tibialis anterior and vastus medialis) we performed a separate 3 × 3 within-subjects analysis of variance with factors word category (arm, leg or abstract) and task condition (respond to the letter 'R', respond to arm words, or respond to leg words). These ANOVAs were done on both time scales (short and long).

The second analysis directly looked at the correspondence between word category and muscle. To this end we coded the data such that EMG traces obtained with arm words with the upper body muscles and leg words with lower body muscles were labeled 'congruent'. EMG traces obtained with arm words with the lower body muscles and data obtained with leg words with upper body muscles were labeled 'incongruent'. Abstract words were not taken into account. Furthermore, we averaged both high attention conditions. The data set thus created was analyzed using a 2 × 2 × 4 within-subjects analysis of variance with the following factors; muscle-word correspondence (congruent, incongruent), attention (low, high), and muscle (the 4 muscles recorded). Similar to the previous analysis, this ANOVA was done on both time scales (short and long). Note that putative effects of semantics will show up as a main effect of muscle-word correspondence, possibly mediated by attention and/or muscle type.

We adopted a *p*-value of 0.05 throughout. Effect sizes are reported as partial eta-squared.

3. Results

The first analysis revealed the following effects; For the vastus muscle at 0–500 ms we found a main effect of word category, $F(2, 22) = 4.032$, $p = 0.023$, partial eta-squared = 0.268. The mean EMG activity for the arm words was 20.8 μV, for the leg words it was 20.6 μV and for the abstract words it was 20.5 μV. Follow-up pairwise *t*-tests tests revealed that the difference in EMG activity was significant between arm words and abstract words, $t(11) = 2.309$, $p < 0.05$; the difference between arm words and leg words was marginally significant, $t(11) = 2.144$, $p = 0.055$, and the difference between leg words and abstract words was not significant ($p > 0.1$).

For the tibialis muscle at 0–3000 ms the interaction between word category and task condition was significant, $F(4, 44) = 2.711$, $p = 0.042$, partial eta-squared = 0.198. Inspection of the means revealed that this interaction was due to the 2 attention conditions. For the condition where subjects had to respond to the leg words it was found that that rectified EMG (rEMG) activity with leg words was significantly lower than with arm words, $t(11) = 3.227$, $p < 0.01$ and lower than with abstract words, $t(11) = 2.638$, $p < 0.05$. In other words, when subjects attended to leg words EMG activity was lowest in trials requiring a 'yes' response. The same contrasts for the arm condition were not significant.

Finally, the same interaction was significant for the biceps muscle at 0–500 ms, $F(4, 44) = 3.160$, $p = 0.023$. This interaction appeared due to the low-attention condition; muscle activity was significantly higher for arm words than abstract words, $t(11) = 2.583$, $p < 0.05$, and activity was higher for arm words than leg words, $t(11) = 2.349$, $p < 0.05$, whereas the difference between leg words and abstract words was not significant. The same contrasts for the two high-attention conditions was not significant.

The second analysis revealed the following effects; for the short time scale the interaction between muscle-word correspondence and attention was significant, $F(1, 11) = 10.303$, $p < 0.008$, partial eta-squared = 0.484. Follow-up pairwise *t*-tests tests revealed that the difference in muscle activation between congruent and incongruent words was significant for the high-attention condition; $t(11) = 3.498$, $p < 0.005$, whereas the same contrast for the low-attention condition was not significant. The means for the high-attention congruent and incongruent words was 22.61 μV and 22.74 μV, respectively. In other words, we found that –over all muscles– activity was significantly lower in trials where word category and muscle were matching than when they were not matching, but only in the high attention conditions. Finally, the same analysis done on the longer time scale (0–3000 ms) revealed no significant effects. EMG values for across all conditions are shown in Fig. 1.

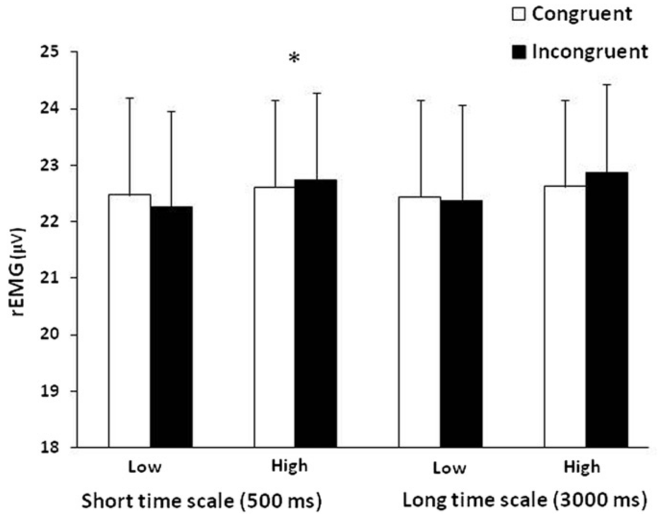

Fig. 1. Mean rectified EMG activity, separately for both attention conditions (high/low), both types of muscle-word correspondence (congruent/incongruent) and both time scales (0–500 ms/0–3000 ms). The asterisk denotes a significant difference between the conditions. Error bars represent standard errors of the mean.

4. Discussion

To our knowledge, this is the first study to examine modulations of spontaneous muscle activity in response to language processing. Using surface EMG we tested whether activity in the motor cortex related to verb processing (repeatedly demonstrated in other studies) would "spill over" to the motor periphery. If reading action verbs related to various activities were to activate somatotopic motor areas via a process of partial simulation or re-enactment of these activities, this could lead to a change in baseline activity of selected muscles. This was tested by presenting a set of arm-related words and leg-related words, and assessing its effect on upper and lower body muscles. We additionally reasoned that effects of verbal category on muscle activity would only show up when there is cognitive involvement with the verbal material, and not when the verbs are processed on a superficial level. To this end, we compared two types of instructions; one requiring semantic classification of the stimuli and one requiring orthographic classification of the stimuli, based on the presence of a target letter.

Our first analysis looked specifically at effects within each muscle. The ANOVA revealed modest effects, and that were not related to our central question. One potentially interesting finding was that a 'yes' response was associated with somewhat reduced muscle activity in tibialis muscle when subjects attended to leg words compared to a 'no' response. We also found for two muscles (vastus and biceps) an increase in activity with arm words relative to leg or abstract words. Perhaps this effect was related to ease of recognition of the verbs, and not to mental simulation per se. Note that some of these effects were borderline significant, and we did not adopt a correction for multiple comparisons. Numerous methods been proposed in the literature (some more conservative than others), and some of our significances would undoubtedly disappear. But given that the observed effects were not related to the main question, we decided to report the uncorrected p-values.

Our second analysis directly compared congruent word-muscle pairs with incongruent ones. The most important finding was a reduction in EMG activity when the pairs were congruent (e.g., response of arm muscle activity to arm words) compared to when they were incongruent. Importantly, this effect only showed up when the words were attended to, thus providing evidence of attention-modulated effects of language processing on resting-state EMG.

Two things should be noted to this effect. First, the effect —although significant— was overall rather small. This is evidenced by the fact that the analyses on individual muscles did not reveal the critical interaction between attention and word category, and the effect only showed up when data were collapsed over all four muscles recorded. So, we deem it premature to attach a lot of weight to this result. Second, the effect (if found to be robust) was unexpected because, if anything, we expected to find an increase in activation (cf. Niedenthal et al., 2009), and not a decrease. We would like to offer the following tentative explanation, and that may inform future research using a comparable paradigm as ours. We speculate that our subjects were engaged in a process of highly selective motor inhibition upon reading the action words. Motor inhibition has been observed for example on a cortical level by Tomasino et al. (2010); their subjects read either positive imperatives (e.g., "do grasp"), or negative imperatives (e.g., "don't write"). Analysis of neural activity obtained with fMRI revealed under both conditions that the motor cortex was active, but significantly less so when negative imperatives were processed. It could be the case that our subjects, who were asked to lay motionless and relaxed, in fact suppressed their motor activity upon reading the verbs. This would of course have to occur in a highly selective manner, as the words were presented in a random order, so subjects did not know in advance whether the upcoming word would relate to movements with the arms or the legs. Motor inhibition has also been observed in studies of motor imagery. Guillot, Di Rienzo, MacIntyre, Moran, and Collet (2010) published a review on the relation between motor imagery (MI) and the execution of actual movements. That paper demonstrated that MI and motor performance shared important neural substrates, but that the main difference between the two involved inhibition of motor commands. With respect to spontaneous muscle activation, the review of Guillot et al. (2010) showed that the literature is inconsistent; yet the majority of studies reveal no effects of MI ("muscle quiscence") on muscle activity, or a slight increase. With respect to our experiment, it could be that reading the action verbs accessed the same neural structures that are involved in MI. Upon reading the verbs a process of active motor inhibition is set in motion, leading to muscle silence, or perhaps even a slight reduction.

An unresolved question is why we found little or no effects of action verb processing on selected muscles in the limbs, whereas studies examining spontaneous activity of facial muscles with emotion words (Bayer et al., 2010; Niedenthal et al., 2009) found robust effects. It could be that the effects observed with facial muscles are specific to emotion per se. Understanding actions and understanding emotions likely involve different neural circuits, e.g., related to empathy. Relatedly, facial muscles that are involved in emotional expressions such as smiling are innervated by the limbic system, which connects in a direct (uncrossed) pathway via the brainstem with facial muscles. In contrast, activity in muscles that are involved in purposeful activities, as in our experiment, has a cortical (motor and premotor) origin. So it could be that reading emotion words primed the limbic system, which –in turn– activated the involuntary emotion circuits. Finally, it could be that cortical motor activity is blocked at the level of the brainstem and spine (cf. Guillot et al., 2010), whereas cortical innervation of the face proceeds via the 7th cranial nerve, which synapses in the pons and from there activates the facial muscles, thus without entering the spine. Although this line of thought is premature, it demonstrates that there are important functional and neuroanatomical differences between the voluntary motor system and emotion system that may be responsible for the divergent findings.

In conclusion, we found little evidence of spontaneous muscle activity with semantic processing of action verbs. More precisely, we found an unexpected decrease in muscle activity with congruent muscle-word pairs relative to incongruent pairs. The effect was rather small and certainly warrants further investigation. Given that our overall EMG results were modest, whereas brain imaging studies show big and reliable effects of language on activity in the motor cortex, we conclude that embodiment effects likely reside in partially overlapping cortical circuits related to motoric and linguistic processing, and that the motor periphery is to a large extent shielded from shared activity in these circuits.

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References

Aziz-Zadeh, L., Wilson, S. M., Rizzolatti, G., & Iacoboni, M. (2006). Congruent embodied representations for visually presented actions and linguistic phrases describing action. *Current Biology, 16*, 1818–1823.

Bak, T. H., & Hodges, J. R. (2004). The effects of motor neurone disease on language: further evidence. *Brain and Language, 89*, 354–361.
Bayer, M., Sommer, W., & Schacht, A. (2010). Reading emotional words within sentences: the impact of arousal and valence on event-related potentials. *International Journal of Psychophysiology, 78*, 299–307.
Boulenger, V., Mechtouff, L., Thobois, S., Broussolle, E., Jeannerod, M., & Nazir, T. A. (2008). Word processing in Parkinson's disease is impaired for action verbs but not for concrete nouns. *Neuropsychologia, 46*, 743–756.
Carlson, R. A., Avraamides, M. N., Cary, M., & Strasberg, S. (2007). What do the hands externalize in simple arithmetic? *Journal of Experimental Psychology: Learning, Memory & Cognition, 33*, 47–56.
Dru, V., & Cretenet, J. (2008). Influence of unilateral behaviors on the judgment of valenced stimuli. *Cortex, 44*, 717–727.
Eder, A. B., & Klauer, K. C. (2009). A common-coding account of the biderectional evaluation-behavior link. *Journal of Experimental Psychology: General, 138*, 218–235.
Fischer, M. H., & Zwaan, R. A. (2008). Embodied language—a review of the role of the motor system in language comprehension. *Quarterly Journal of Experimental Psychology, 61*, 825–859.
Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin and Review, 9*, 558–565.
Guillot, A., Di Rienzo, F., MacIntyre, T., Moran, A., & Collet, C. (2010). Imagining is not doing but involves specific motor commands: a review of experimental data related to motor inhibition. *Frontiers in Human Neuroscience, 6*, 1–22.
Hauk, O., Johnsrude, I., & Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron, 41*, 301–307.
Herrera, E., & Cuetos, F. (2012). Action naming in Parkinson's disease patients on/off dopamine. *Neuroscience Letters, 513*, 219–222.
Hirschfeld, G., & Zwitserlood, P. (2012). Effector-specific motor activation modulates verb production. *Neuroscience Letters, 523*, 15–18.
Niedenthal, P. M. (2007). Embodying emotion. *Science, 316*, 1002–1005.
Niedenthal, P. M., Winkielman, P., Mondillon, L., & Vermeulen, N. (2009). Embodiment of emotion concepts. *Journal of Personality and Social Psychology, 96*, 1120–1136.
Pulvermüller, F. (2012). Meaning and the brain: the neurosemantics of referential, interactive, and combinatorial knowledge. *Journal of Neurolinguistics, 25*, 423–459.
Pulvermüller, F., Härle, M., & Hummel, F. (2001). Walking or talking? Behavioral and neurophysiological correlates of action verb processing. *Brain and Language, 78*, 143–168.
Tomasino, B., Weiss, P. H., & Fink, G. R. (2010). To move or not to move: imperatives modulate action-related verb processing in the motor system. *Neuroscience, 169*, 246–258.