At the interface between action verbs and grip force

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INTRODUCTION

Action verbs and motor actions activate similar cortical brain areas (Price et al., 1994; Grafton et al., 1998). An increasing number of studies reveal that the sensorimotor components of word meaning activate cortical regions overlapping with the neural systems involved in the planning and execution of actions described by the words. For example, processing verbally presented actions activates corresponding sectors of the motor system, depending on the effector (face, hand or foot) used in the listened-to action (e.g. Hauk et al., 2004). Moreover, in sign language there is a close semantic relationship between the gestures and the function of the object expressed (e.g., hammer or scissors in American Sign Language), suggesting that transmodal processes are implicated in pragmatic representations. These studies and numerous observations strongly suggest that the brain areas subtending object-oriented actions are closely related to the brain areas involved with language (e.g., Gentilucci & Dalla Volta, 2008). Recently, Boulanger et al. (2006) showed that verbs related to manual action could perturb reaching movements. Since reaching and grasping are intimately linked (e.g. Frak et al., 2006) in the present study we test whether manual action verbs could also alter aspects of grasp, such as grip force. Reaching is a process with a recognized bi-hemispheric activity involving the proximal musculature. Grasping with the preferred hand implicates distal muscles under — as is the case for verbal system — left hemispheric control.

Methods

Six right-handed monolingual French native volunteers (medium age: 23) participated in this study . A total of 35 nouns and 35 verbs, controlled for frequency, number of letters, number of syllables, bi- and trigram frequency served as stimuli. All verbs denoted actions performed with the hand or arm (e.g., write, throw) while nouns referred to imaginable concrete entities without specific motor associations (e.g., mill, cliff) and were used as control words. Words that could be used as both nouns and verbs were excluded. Digitized lists of words were generated from the 70 items with one randomly selected target word (noun or verb) repeated 17 times. Participants thus listened to a total of 86 items. Mean word duration was 684 ms and there was an interval of 1000 ms between word presentations. Word order was randomized between subjects.

Participants wore headphones and were seated on a chair without armrests, facing a table on which an instrumental cylinder (Bourbonnais et al., 2008) was placed at a distance of 53.5 cm from their chest (**Figure 1**). They were asked to lift the cylinder with the thumb and index finger of the right hand and hold it at about 5 cm above the table (**Figure 2**). Grip orientation was natural and participants maintained this position by flexing the shoulder while keeping the elbow in full extension. Participants listened to the list of words and silently counted the occurrence of the target word while performing this motor task. The target word was an action verb in one condition, and a noun in the other. In control conditions, the same motor task was performed for the same duration but without listening to the word stimuli. At the end of the session, the cylinder was lowered on the table and participants were asked to give the number of times the target word was presented. Both experimental and control conditions were randomly presented and subjects kept their eyes closed for the duration of the experiment. The six channels (Fx. Fy, Fz, Mx, My, Mz) from the instrumented cylinder system were recorded at 100 Hz per channel and the beginning of the acquisition was synchronized with the beginning of the words output

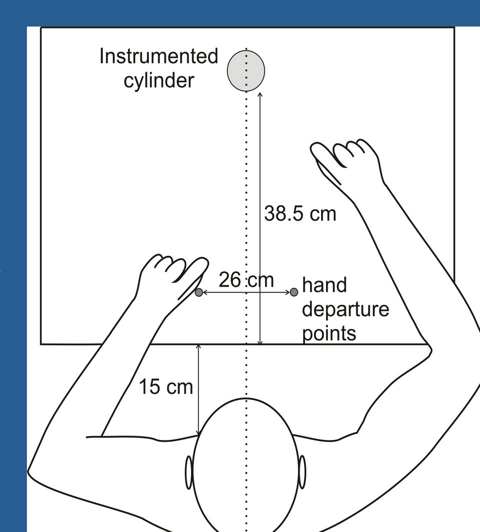

Figure 1

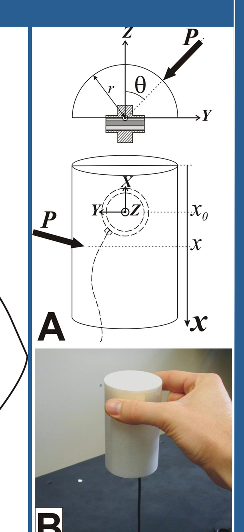

Figure 2

Data analysis

Prior to data analysis, each signal component was filtered at 10 Hz with a fourth-order, zero-phase, low-pass Butterworth filter. The grip force was computed by taking the resultant force of Fx, Fy and Fz. Data were then segmented from the onset of a word to the onset of the following word. Since the level of force applied on the cylinder differed between subjects, each segment of the signal amplitude was normalized by subtracting the lowest point value and dividing the result by the span range (max – min value), thus yielding values ranging between 0 and 1. As the number of target words was smaller than that of non targets (17 vs. 34, respectively) a random selection of 17 non-target words spanned across the session were extracted from each condition to be used in the data analysis.

Results

Figure 3 shows the grand mean of normalized grip force amplitude of action words and non-action words when they served as targets. Data are plotted in a time window of 0.8s from the onset of the word stimulus, which corresponds approximately to the length of the longest word. When the target word was an action word (AT), but not when it was a non-action word (NAT), an abrupt drop of signal amplitude was observed around 0.38s following word-onset, which lasted for about 150 ms. The colored region in the figure indicates the time window (from 0.26s to 0.43s after stimulus onset) within which grip force amplitude differed significantly between the two conditions ($p<0.05$, two tailed paired t-test).

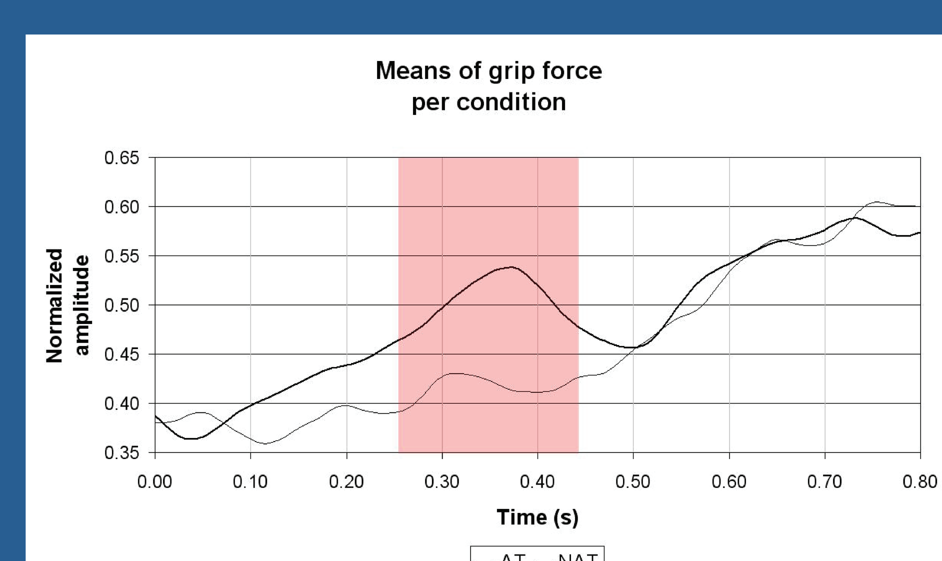

Figure 3 – Mean grip force / condition

DISCUSSION

Until now, it was unclear when processing of linguistic information (i.e., action words) starts to affect motor behavior (Nazir et al., 2008). The present results show that online analysis of variations in grip force allows determining when this effect takes place. A number of interpretations can be offered for the fact that the processing of action words and processing of the corresponding actions share similar brain resources. A first possibility is that an action word activates cerebral motor areas since it brings about a motor image of the verbally presented action — suggesting that activation of the motor system takes place before lexical processing is complete. The motor simulation thus provides the pragmatic knowledge congruent with the underlying action and complements the semantic recognition of the action-related word. That the motor activation is topographically related to the action evoked by the word argues in favor of this view and suggests that the motor image is a central cognitive phenomenon (Jeannerod, 2006). Pulvermüller et al. (2005) had proposed a contrasting view of the motor activation induced by action words: activation is not the consequence of the relationship between the action words and the simulated actions but rather that it is inherently linked with lexical-semantic processing. A key argument for this interpretation is that the activation of the motor system occurs early in the course of presentation of the word. The results of the present study indicate that these two views can actually be integrated along a motor continuum of linguistic information. The observed increase in grip force occurring with the presentation of action verbs can be interpreted as the progression of the spontaneous muscular facilitation evoked by the action verb, from its lexical-semantic processing (Sereno et al., 1998) until the inhibition of the muscular activity evoked by the motor simulation (Jeannerod, 1994). The occurrence of electromyographic activity during the simulation of a motor gesture has been interpreted as an incomplete inhibition of the motor output (Lebon et al. 2008). The action words elicit an increase in muscular activity that must be inhibited. To our knowledge, this is the first time that a demonstration of this phenomenon is made, indicating that the structures that participate in the retrieval of action words also partake in the control of motor behavior. Thus, simulation of action is at the interface between action word comprehension and motor production (Prinz, 1997).

It is important to note that the variations in force level were subliminal as subjects did not report, even when specifically questioned, that they were aware of observable changes in grasp force between the different experimental conditions. This suggests that onset of linguistic information can generate motor simulations, producing peripheral muscle changes that are not under conscious control or awareness.

The crosstalk between language processes and overt motor behavior provides unambiguous evidence that action words and motor action share common cortical representations, suggesting that cortical motor regions are indeed involved in action word retrieval. As this happens during a manual action, such as holding an object with a precision grasp, it also means that the muscular changes related to the simulation and the action, although closely tied, constitute separable elements. This distinction has been reported following damage to frontal brain areas (Sirigu et al., 1996). Furthermore, hemiplegic patients are capable of simulating manual actions even though they are paralyzed as a result of brain injuries in M1 (Johnson-Frey, 2004).

The approach presented here opens up a new field of research investigating the impact of complex language and speech activity in healthy subjects and clinical populations with movement or language disorders.

REFERENCES

Boulenger V. et al. (2006) J Cogn Neurosci 18:1607-1615.
Bourbonnais D. et al. (2008) J Neuroeng Rehabil 5:2doi:10.1186/1743-0003-5-2.
Frak V. et al (2006) Brain Cogn 60:43-48.
Gentilucci M. & Dalla Volta R (2008) Q J Exp Psychol 61:944-957.
Grafton ST. et al. (1998) J Neurosci 18: 9420-9428.
Hauk O. et al. (2004) Neuron 41:301-307.
Jeannerod M (1994). Behav Brain Sci 17:187-245.
Jeannerod M (2006) Motor cognition: what actions tell the self. (Oxford University Press).
Johnson-Frey SH (2004) Brain Cogn 55:328-331.
Lebon F et al. (2008) Science et motricité 64-2:11-34.
Nazir TA. et al. (2008) Q J Exp Psychol 61:933-43.
Price CJ. et al. (1994) Brain 117: 1255–1269.
Prinz W (1997) Eur J Cogn Psychol 9 129-154.
Pulvermüller F (2005) Nat Rev Neurosc 6:576–582.
Sereno SC et al. (1998). Neuroreport 9: 2195–2200
Sirigu A. et al (1996) Science 273:1564-1566.

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