Psychological Research
DOI 10.1007/s00426-011-0371-2

ORIGINAL ARTICLE

How the motor system handles nouns: a behavioral study

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Received: 4 March 2011 / Accepted: 26 July 2011

Abstract It is an open question whether the motor system is involved during understanding of concrete nouns, as it is for concrete verbs. To clarify this issue, we carried out a behavioral experiment using a go-no go paradigm with an early and delayed go-signal delivery. Italian nouns referring to concrete objects (hand-related or foot-related) and abstract entities served as stimuli. Right-handed participants read the stimuli and responded when the presented word was concrete using the left or right hand. At the early go-signal, slower right-hand responses were found for hand-related nouns compared to foot-related nouns. The opposite pattern was found for the left hand. These findings demonstrate an early lateralized modulation of the motor system during noun processing, most likely crucial for noun comprehension.

Introduction

The embodiment approach to language is relatively recent and contrasts with a more classical view of language processing, where representations are viewed as amodal (e.g., Fodor, 1975; Pylyshyn, 1984; Mahon & Caramazza, 2005). Embodiment theory claims that language understanding involves the activation of the same neural substrates, sensory and motor, activated when one experiences the action or object to which a word refers. In the recent years, there has been growing evidence for this claim (Lakoff, 1987; Glenberg, 1997; Barsalou, 1999; Pulvermüller, 2002; Gallese, 2003; Zwaan, 2004; Gallese & Lakoff, 2005; Zwaan & Taylor, 2006; Fischer & Zwaan, 2008), although some still refute the theory (Mahon & Caramazza, 2008).

Thus far, the work in this field has focused on language referring to action, i.e., action verbs or sentences. A variety of behavioral and neurophysiological approaches have shown evidence for activation of the motor system during processing of action-related language material. For example, there are behavioral studies showing slower reaction times when the effector used to respond is also involved in actual execution of the action expressed by the presented linguistic material (Buccino et al., 2005; Boulenger et al., 2006, 2008; Sato, Mengarelli, Riggio, Gallese, & Buccino, 2008; Dalla Volta, Gianelli, Campione, & Gentilucci, 2009). Other behavioral studies have demonstrated that the execution of a motor response is facilitated by the comprehension of sentences that describe actions taking place in the same direction as the motor response (e.g., Glenberg & Kaschak, 2002). This action-sentence compatibility effect (ACE) occurs when the response is performed at an early point in the comprehension of the sentence or right before its end (Kaschak & Borreggine, 2008). More specifically, Taylor and Zwaan (2008) observed that, within the sentence, ACE is time-locked to the comprehension of the verb that defines the action or to a post-verb adverb that does not shift focus from the action. Together these findings were interpreted as resulting from an interaction between activation of the motor system for language understanding and activation for response.

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Published online: 31 August 2011

Further evidence comes from neurophysiological and brain imaging techniques, which showed that presentation of verbs associated with different effectors, results in somatotopic activation of motor areas (Pulvermüller, Härle, & Hummel, 2001; Hauk, Johnsrude, & Pulvermüller 2004; Tettamanti et al. 2005) and common activation in Broca's area for action-related sentences and their action counterparts (Baumgaertner, Buccino, Lange, McNamara, & Binofski, 2007). There is also evidence from TMS work showing a modulation in the motor evoked potential for a muscle of a given effector, associated with the presented verb (Buccino et al. 2005). This occurs when the TMS pulse is applied at the end of the stem of the acoustically presented verb (for contrasting findings see Postle, McMahon, Ashton, Meredith, & de Zubicaray, 2008; Papeo, Vallesi, Isaja, & Rumiati, 2009). Further evidence for an early motor modulation comes from Pulvermüller, Shtyrov, and Ilmoiemi (2005) who, using MEG, showed motor activation occurring within 170 ms after the acoustic presentation of action-related words. Further, Pulvermüller, Hauk, Nikulin, and Ilmoniemi (2005) found that the magnetic stimulation of hand and leg motor and premotor areas in the left hemisphere, 150 ms after word onset, led to facilitation in recognizing meaningful arm and leg action-related verbs among meaningless pseudo words, briefly presented on a computer screen. These findings, and especially those using techniques with high temporal resolution (TMS, EEG, MEG) provide strong evidence for an early, and likely automatic, involvement of the cortical motor system in the processing of action-related language.

The mechanism through which words referring to actions, i.e., verbs, could elicit the motor representations for action itself can be explained in terms of the mirror neuron mechanism. Mirror neurons are a set of neurons found in premotor and parietal cortex which are active both when an individual acts and when they observe action or hear action-related sounds (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolotti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; Buccino et al. 2001; Kohler et al., 2002; Ferrari, Gallese, Rizzolatti, & Fogassi, 2003; Keysers et al., 2003; Aziz-Zadeh, Iacoboni, Zaidel, Wilson, & Mazziotta, 2004). The system also appears to have a somatotopic organization (Buccino et al. 2001; Wheaton, Thompson, Syneniotis, Abbot, & Puce, 2004; Sakreida, Schubotz, Wolfensteller, & von Cramon, 2005). It is therefore hypothesized that words referring to action could employ the same system to transfer motor representation from the speaker to the listener.

As we have seen there is ample evidence for a role of the motor cortex in action-language understanding. There has been much less focus on noun processing, even though embodiment theory predicts that nouns should elicit a similar response in the motor system. According to classical linguistic theories, verbs and nouns have diverse neural underpinnings (see Vigliocco, Vinson, Druks, Barber & Cappa, 2011 for review). Indeed patient studies (e.g., Tranel, Adolphs, Damasio, & Damasio, 2001; Shapiro & Caramazza, 2003), functional imaging (e.g., Tyler, Bright, Fletcher, & Stamatakis, 2004; Shapiro, Moo, & Caramazza, 2006), electrophysiological approaches (e.g., Pulvermüller, 1999; Pulvermüller, Lutzenberger, & Preissl, 1999) and repetitive TMS (e.g., Shapiro, Pascual-Leone, Mottaghy, Gangitano, & Caramazza, 2001; Cappa, Sandrini, Rossini, Sosta, & Miniussi, 2002) supported the notion that different neural structures are recruited during processing of nouns and verbs.

If nouns are also embodied, and nouns refer to objects, it is worth assessing how the motor cortex reacts to object presentation. It is known that the manipulation of objects involves a fronto-parietal circuit in the brain, both of monkeys (Rizzolatti, Scandolara, Gentilucci, & Camarda, 1981; Rizzolatti et al., 1988; Kurata & Tanji, 1986; Taira, Mine, Georgopulos, Murata, & Sakata, 1990; Sakata, Taira, Mine, & Murata, 1992; Hepp-Reymond, Husler, Maier, & Qi, 1994; Jeannerod, Arbib, Rizzolatti, & Sakata, 1995; Rizzolatti, Fogassi, & Gallese, 2004) and humans (Binkofski et al., 1999) reflecting sensori-motor transformation. Perception of object-related actions and objects alone also modulates activity in the motor system. Evidence exists for this effect both in non-human primates and humans. In particular, for monkeys, a set of neurons now referred to as "canonical neurons", have been shown to respond during the perception of objects which can be manipulated (Rizzolatti et al., 1988; Murata et al. 1997; Raos, Umiltà, Fogassi, & Gallese, 2006; Umiltà, Brochier, Spinks, & Lemon, 2007). Using different techniques (fMRI, PET) similar findings have been demonstrated in the human brain (Grèzes & Decety, 2002; Grèzes, Armony, Rowe, & Passingham, 2003; Grèzes, Tucker, Armony, Ellis, & Passingham, 2003). In sum, the perception of objects that have the potential for being manipulated, activate the very system responsible for the actual manipulation. In other words, the brain responds to the affordances (Gibson, 1977, 1979) of an object. A recent paper highlights the relationship between motor activity and the properties/affordances of manipulable objects by showing that changing the physical (affording) properties of the object, changes the motor response to it (Buccino, Sato, Cattaneo, Rodà, & Riggio, 2009). It seems likely that in the same way that mirror neurons could underlie verb processing, canonical neurons could underlie noun processing and enable activation of the motor system.

Few studies have been dedicated to addressing the issue of the activation of the motor cortex during language tasks, in which nouns are used alone as stimuli. One example of a

TMS study using nouns presented alone does indicate an involvement of ventral premotor cortex (PMv) in the processing of tool-related words (Cattaneo, Devlin, Salvini, Vecchi, & Silvanto, 2010) but does not address further timing effects or narrower semantic categories. As far as we know, there are no such available neuroimaging studies but nouns have been used preceded by other word forms (e.g., Hoenig, Sim, Bochev, Herrnberger, & Kiefer, 2008).

In behavioral studies, there is some indication that the presentation of nouns can interact with motor activity. In a kinematic study, Glover, Rosenbaum, Graham, and Dixon (2004) showed that reading nouns referring to small and large objects (e.g. "grape" or "apple") that require a precision grip or a power grip, respectively, interfered with the planning of grasping movements directed to targets of different size. Similarly, Tucker and Ellis (2004), using a categorization task in which nouns referring to different size objects were used as stimuli, and responses were given by manipulating a mechanical device requiring a precision grip or a power grip, found faster performance when there was compatibility between the grip implied by the noun and the grip required to respond. A consistency effect between action preparation and noun processing was subsequently observed by Lindemann, Stenneken, van Schie, and Bekkering (2006) who showed that planning grasping-to-use movements directed toward everyday objects (e.g., a glass) facilitates the semantic activation of nouns (e.g., mouth) that are related to the action goals of the object use. Myung, Blumstein, and Sedivy (2006) showed that words denoting man-made objects that share elements of manipulation knowledge (e.g. "piano" and "typewriter") prime one another in a lexical decision task. More specifically, Bub, Masson and Cree (2008) showed that the manipulation knowledge evoked by words of man-made objects includes details of specific hand movements associated with both the overall volumetric properties of objects and their conventional use. Although the interaction between noun processing and motor activity has already been addressed in behavioral studies, the issue of the timing remains. To our knowledge, only Boulenger et al. (2006, 2008) assessed the time course of linguistic-motor activation using nouns, but, as these nouns referred to non-graspable objects, they simply revealed the temporal relation between action verb processing and overt motor behavior.

In the present study, we investigated the involvement of the motor system at an early time point in noun processing. Right-handed participants were presented with foot-related nouns, hand-related nouns, and abstract nouns. They were required to indicate by hand responses (left or right) when a word was concrete. Effects were tested at an early (150 ms) and a late (1,150 ms) go-signal delivery. The time points were chosen to coincide with those of a previous behavioral experiment on verbs, which showed a significant motor modulation early in word processing, an effect which disappeared by the late time point (Sato et al. 2008). Furthermore, we tested the involvement of left and right hemisphere primary motor areas (right or left hand). We predicted that if a sector of the motor system is involved in language processing and at the same time involved in a motor response, then interference should occur, resulting in slowed reaction times. More specifically, we predicted the involvement of the hand area in processing hand-related but not foot-related nouns, with this effect being confined to the left hemisphere, given its specialized involvement in language processing in right-handed individuals.

Methods

Participants

Forty-six students of the University of Parma (26 females) took part in the experiment as volunteers. The age range of participants was 18–29 years. All participants were native Italian speakers. All were right-handed (Mean Edinburgh Handedness Inventory Score ± SD, 0.83 ± 0.14, Oldfield, 1971), had normal or corrected-to-normal vision and reported no history of language disorders. None of them were aware of the purpose of the experiment.

Stimuli

Twenty-four Italian nouns were selected as stimuli (see "Appendix"): eight nouns referring to objects normally used with the hand (e.g., 'matita', 'pencil'), eight referring to objects related to foot action (e.g., 'scalino', 'step') and eight expressing an abstract content (e.g., 'gelosia', 'jealousy'). Nouns in the three categories were matched for syllable number (average values for hand-related, foot-related and abstract nouns: 3, 3.37 and 3.25; $F[2,21] = 1.81$, $p = .19$), word length (average values: 7.62, 7.62 and 7.25; $F[2,21] = 0.31$, $p = .74$) and lexical frequency (2.43, 1.67, and 3.29 in occurrences per million, Laudanna, Thornton, Brown, Burani, and Marconi 1995, ~3,798,000 words; $F[2,21] = 0.748$, $p = .485$).

Procedure

The experiment was carried out in a sound-attenuated room, dimly illuminated by a halogen lamp directed toward the ceiling. Participants sat comfortably in front of a computer screen at a distance of about 57 cm from it. Participants were asked to carefully read nouns and to give a motor response, as fast and accurate as possible, by pressing with the index finger a key on the computer

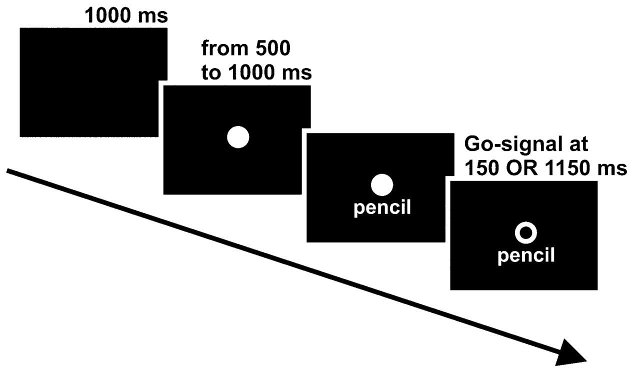

Fig. 1 Experimental procedure

keyboard centered on participants' body midline, when the noun expressed a concrete object, and refrain from responding when the noun expressed an abstract content (go-no go paradigm). Participants were randomly divided into two groups of 23 each. The first group gave the motor response using the right hand, whereas the second group gave the motor response using the left hand. Stimuli were presented at the center of the computer screen and written in lowercase Arial font (point size = 18) on a black background. Each trial started with a red circle presented at the center of the screen. After a variable delay of 500–1,000 ms (in order to avoid a response habituation), a noun was presented. The red circle changed to green either 150 ms (early delivery) or 1,150 ms (delayed delivery) after noun presentation onset. The color change of the circle was the "go" signal for the response when the noun expressed a concrete content (see Fig. 1). Participants received feedback after pressing the key when a noun expressing abstract content was presented ("ERROR"), as well as after pressing the key prior to go signal presentation ("ANTICIPATION"), or after taking 2 s to respond ("YOU HAVE NOT ANSWERED"). The intertrial interval was 1 s. During this period the PC screen remained blank. Stimulus presentation and response time collection were controlled using the software package E-Prime, version 1.1. (Psychology Software Tools, Inc.). The experiment consisted of one practice block and two experimental blocks. In the practice block, participants were presented with 24 nouns which differed from those selected as stimuli (66.6% concrete nouns and 33.3% abstract nouns). In each experimental block, the 24 nouns selected as stimuli were randomly presented for each of the two time of go-signal delivery (150 and 1,150 ms). Thus, the experiment, which lasted about 15 min, consisted of 64 go trials (8 hand-related nouns plus 8 foot-related nouns × 2 time of go-signal delivery × 2 repetitions) and 32 no-go trials (8 abstract nouns × 2 time of go-signal delivery × 2 repetitions), and 24 practice trials, for a total of 120 trials. To sum up, the experiment used a 2 × 2 × 2 mixed factorial design with Response Hand (right, left) as a between-subjects variable, and Time of go-signal delivery (early, late) and Noun Type (hand-related, foot-related) as within-subject variables.

Results

Trials with errors were excluded without replacement. Errors included all cases in which participants did not give a response to a concrete word (0.07% of total trials), cases in which responses were given before the go-signal onset (1.78% of total trials), and cases where participants responded to an abstract word (2.47% of total trials). Errors were not analyzed separately given they were extremely rare. No participants were excluded from the analysis since their accuracy was at least 90%. Before being analyzed, response times (RTs) measured for correct trials were screened for outliers. RTs below 130 ms (0.14% of total trials) or above 1,000 ms (0.28% of total trials) were omitted from the analysis. This cutoff was established so that no more than 0.5% of correct RTs were removed (Ulrich and Miller 1994).

Median values of remaining RTs were calculated for each combination of time of go-signal delivery and noun category. These data entered in a mixed ANOVA with Time of go-signal delivery (early, late) and Noun Type (hand-related, foot-related) as within-subject variables, and Response Hand (left, right) as a between-subject variable.

The ANOVA revealed that the main effect of Time ($F[1,44] = 422.86, p < .001$) was significant. The two-way interaction between Response Hand and Noun Type ($F[1,44] = 6.93$, $p < .02$) and the three-way interaction among Response Hand, Time and Noun Type ($F[1,44] = 13.75, p < .001$, see Fig. 2) were also significant.

The main effect of Time of go-signal delivery is due to slower responses at the early (491 ms) than at the delayed (318 ms) delivery of the go signal. Post hoc comparisons (Duncan's Test) were performed in order to understand the significant interaction effects. The two-way interaction between Response Hand and Noun Type indicates that participants who responded with their left hand were faster with hand-related nouns than with foot-related nouns (392 vs. 401 ms, respectively, $p < .01$), whereas response times of participants who responded with their right hand were independent of noun type. Most interestingly, however, the three-way interaction shows that, at the early delivery of the go signal, left-hand responses were faster for hand-related nouns (475 ms) than for foot-related nouns (496 ms, $p < .001$, i.e., facilitation for hand-related nouns), whereas right-hand responses were faster for foot-related nouns (493 ms) than for hand-related-nouns (501 ms, $p < .05$, i.e., interference for

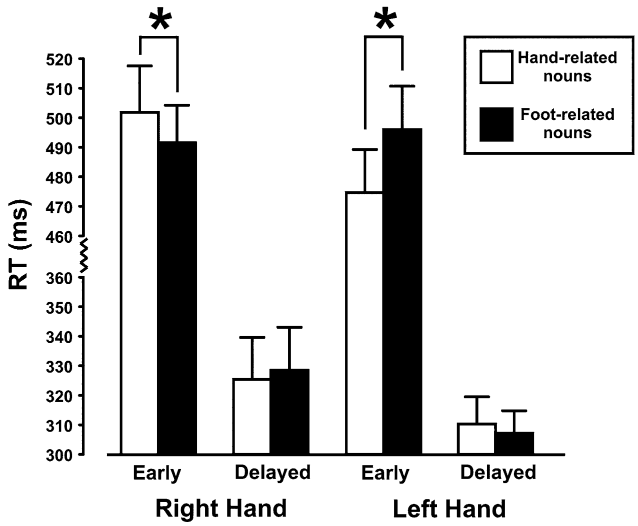

Fig. 2 Results. Columns show the mean of median reaction times as a function of Time of go-signal delivery (early vs. delayed) and Response Hand (left vs. right), separately for hand-related (*open columns*) and foot-related nouns (*filled columns*). *Error bars* are the standard errors of the mean across participants. *Square brackets* indicate significant differences ($p < .05$) between experimental conditions

hand-related nouns). In contrast, at the delayed delivery of the go signal no modulation by Noun Type or Response Hand was observed.

Discussion

We have shown evidence for embodiment of nouns. At the early go signal, participants showed slower response times when they responded with their right hand to hand-related versus foot-related nouns. In contrast, when responding with the left hand, participants showed faster responses to hand relative to foot-related nouns. For the late go signal there was no difference in response times for hand-related versus foot-related nouns for neither the left- nor the right-hand responses.

In summary, the present experiment indicates the early involvement of the motor cortex of the left hemisphere in the representation of nouns referring to manipulable objects. These results show that the motor system is excited not only by the visual presentation of objects (e.g., Chao & Martin, 2000; see also Martin, 2007 for a review), but also by linguistic labels, i.e., nouns, referring to manipulable objects. As mentioned above, the neural basis for this effect could be due to canonical neurons, shown in the monkey to be responsive to the presentation of graspable objects (Rizzolatti et al. 1988; Murata et al. 1997). Consistent findings have also been reported in humans (Grèzes & Decety, 2002; Grèzes et al., 2003a; Grèzes et al., 2003b).

The current study is novel as it indicates that the motor system is modulated by concrete nouns in a way comparable to verbs (Pulvermüller et al., 2001; Hauk et al., 2004; Tettamanti et al., 2005; Buccino et al., 2005; Boulenger et al., 2006; Sato et al., 2008; Dalla Volta et al., 2009), although the two categories are not directly compared here. This suggests that the brain does not distinguish between these grammatical categories, at least in motor terms, and instead may distinguish classes of words in terms of semantics—such as, for example, being an action-related word or not. Previous work (Boulenger et al., 2006, 2008) which failed to find a comparable effect for nouns may be explained by the fact that the nouns employed referred to non-graspable objects.

While we suggest here that mirror neurons are important for action verb processing and canonical neurons for concrete noun processing, we do not want to imply that these neural mechanisms act completely independently. The two types of neurons are, after all, intermingled in the same cortical area and form part of the same motor circuit. It has been proposed that mirror and canonical neurons interact for both the execution and the recognition of actions. It follows that this interaction would also apply to the linguistic domain when concrete nouns and verbs refer to manipulable objects and actions, respectively.

The reported work is also novel in language embodiment literature as it directly compares involvement of the two hemispheres. Our differential pattern of results for the left and right hemisphere is in line with the classical finding of left hemisphere dominance for language processing (Broca, 1861; Ojemann, Ojemann, Lettich, & Berger, 1989; Binder, Frost, Hammeke, Rao, & Cox, 1996; Knecht et al., 2000). It is also in line with findings suggesting a leftward bias for tool processing (Johnson-Frey, Newmann-Norlund, & Graftton, 2005) and the mirror system, thought to precede the human language ability (see Rizzolatti & Arbib, 1998). We found that at the early go-onset in the left hemisphere (right hand) there was an interference for hand-related nouns between linguistic processing and hand motor response, whereas for the right hemisphere (left hand) there was no such interference. In fact the opposite effect was found, with facilitation for hand-related nouns over foot-related nouns when the left hand was used to respond. We have no clear explanation for this different modulation of the two hands and, in our opinion, this finding deserves further investigation. Here we forward a rather speculative proposal to account for the results. Whereas two processes—linguistic processing and motor response—occurred for the left hemisphere at the same time, for the right hemisphere the linguistic task had already been solved and the right hemisphere was primed for response (see Fig. 3). Words related to the hand would be expected to be faster when responding with a congruent

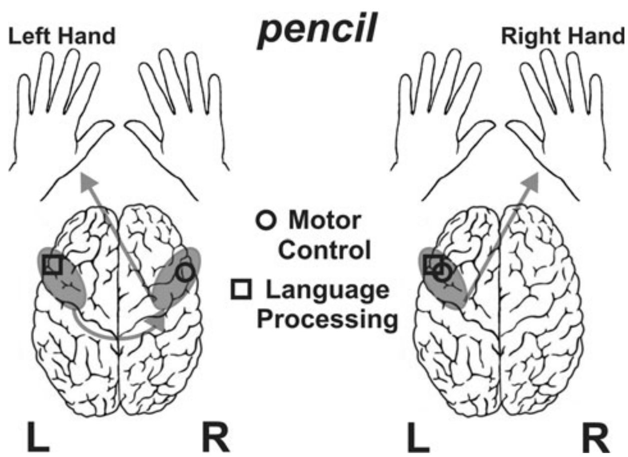

Fig. 3 Schematic representation of the recruitment of the hand area in the left motor cortex during the understanding of hand-related nouns (e.g., pencil). The *right half* of the figure shows that the recruitment of the hand area in the left hemisphere during language processing interferes with the activation of participants' left M1 hand area due to the planning of an overt right hand response. The *left half* of the figure shows no such interference when an overt left hand response is required

effector because the semantics of the presented word had already been accessed and the resultant motor representation could be expected to be bilateral. No significant effects were revealed for the late time period, presumably because at this stage the processes in question are already completed.

At the first glance, the present results are in contrast with those obtained from other studies aimed at assessing ACE, where even at an early request of the response a facilitation of both hands was found (Kaschak & Borreggine, 2008). Regardless of clear methodological differences, two main reasons may explain these different findings. First, in all experiments where ACE was studied participants' responses were never required earlier than 500 ms from the stimulus onset (e.g., Kaschak & Borreggine, 2008), much later than in the present study, where responses were required after 150 ms from the stimulus onset. Since a different modulation of the motor system may occur over time (see below), the present data are not directly comparable with those obtained from ACE experiments for both hands. Second, in ACE experiments there is a strict relationship between the motor content of the sentence and the response required, especially in terms of the direction of movement. It may be speculated that a specific motor program, or even a specific parameter of that motor program, i.e., direction, among those which can be possibly carried out with the hand, is selected and primed (see Buccino et al., 2005). In this respect, the results obtained from ACE experiments fit with the recent finding that the motor system recruitment during language processing is modulated by the sensorimotor specificity expressed by the linguistic material (Marino, Gallese, Buccino, & Riggio, 2011). In the present experiment, as in our previous ones, the interference effect occurs in terms of the effector involved rather than a specific motor program selected.

In this context, it is of worth stressing another novelty of our study, subtle but nonetheless important. Previous behavioral studies providing evidence for an interaction between noun processing and motor activity required subjects to perform very peculiar hand movements, such as grasping blocks (Glover et al., 2004), manipulating mechanical devices (Tucker & Ellis, 2004; Bub et al., 2008) or using objects (Lindemann et al., 2006). In contrast, we were able to show that accessing the meaning of nouns referring to graspable objects can interfere with the execution of much less complex hand movements, such as pressing a button on a keyboard. This finding is in keeping with the idea already pointed out by Lindemann et al. (2006) that the influence of noun understanding on response planning cannot be accounted for by the complexity of motor response, but rather, as evidenced here, by the competition for common resources between hand-related noun processing and hand response preparation.

The present work and previous work on verbs (e.g., Sato et al., 2008; Boulenger et al., 2006; Hauk & Pulvermüller, 2004) shows that motor activity related to linguistic processing occurs early. This finding is important because it testifies that the modulation of the motor system occurs in a period consistent with that for word understanding (Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006). This modulation, thus, rather than being a mere side effect of distinct upstream cognitive processes accompanying language comprehension (Mahon & Caramazza, 2005), can be plausibly considered to play a causal role in solving the comprehension process (for a position different from the one presented here, see Mahon & Caramazza, 2008).

Despite the growing number of studies supporting the early involvement of the motor system in language understanding, it is still a matter of debate at what point the interference effects seen here and elsewhere (e.g., Buccino et al., 2005; Sato et al., 2008) disappears. Chersi, Thill, Ziemke and Borghi (2010) recently proposed that the interference effect is apparent for an early time window (from about 200 up to 400 ms). For a later time window (up to about 850 ms), the modulation becomes facilitatory, as evidenced in some studies (e.g., Olivieri et al., 2004; Pulvermüller et al., 2005; Boulenger et al., 2006, 2008; Scorolli & Borghi, 2007; Borghi & Scorolli, 2009; Papeo et al., 2009). Beyond this no more effects should be observed. As far as we know, no work has specifically examined the time course from early to late. Therefore, the future work will need to clarify the time course of the activation of the motor system in language processing and its effects in more detail.

Taken together the current work and previous results suggest that both verb and noun processing involve the motor system. It follows that the combination of these linguistic items in phrases and sentences would also involve the activation of the cortical motor system in a manner that may parallel the organization of actions. If this is true, the syntax of language may be equivalent to the syntax of action (Dominey, Hoen, Blanc, & Lelekov-Boissard, 2003; Gallese 2007; 2008; Clerget, Winderickx, Fadiga, & Olivier, 2009; Fadiga, Craighero, & D'Ausilio, 2009; Fazio et al., 2009; Pulvermüller & Fadiga, 2010).

Since it has been already shown that the cortical motor system is important for phonology (Fadiga, Craighero, Buccino, & Rizzolatti, 2002; Watkins & Paus, 2004; Wilson, Saygin, Sereno, & Iacobni, 2004; Meister, Wilson, Deblieck, Wu, & Iacoboni, 2007; Möttönen & Watkins, 2009), and that concrete nouns and verbs are represented motorically (see above), this would imply that all aspects of, at least, concrete language, could be dealt with by the cortical motor system (see Gallese, 2008).

Acknowledgments This study was supported by the European Community Grant ICT-216125-ROSSI and by MIUR (Ministero Italiano dell'Università e della Ricerca).

Appendix

See Table 1.

Table 1 Linguistic material used in Experiment 1. For each noun, category, number of letters, number of syllable and relative lexical frequency (number of occurrence per million—Laudanna et al., 1995) are listed

Noun	Type	Letters	Syllable	Lexical frequency	English translation
Forbici	Hand-related	7	3	2.76	Scissors
Tazzina	Hand-related	7	3	0.06	(small) Cup
Spazzola	Hand-related	8	3	1.01	Brush
Forchetta	Hand-related	9	3	2.80	Fork
Pettine	Hand-related	7	3	3.15	Comb
Matita	Hand-related	6	3	6.16	Pencil
Accendino	Hand-related	9	4	0.38	Lighter
Martello	Hand-related	8	3	3.14	Hammer
Pedale	Foot-related	6	3	2.11	Pedal
Pantofola	Foot-related	9	4	0.23	Slipper
Pedana	Foot-related	6	3	2.91	Footboard
Pattini	Foot-related	7	3	0.74	Skate
Gradino	Foot-related	7	3	5.22	Step
Mocassino	Foot-related	9	4	0.01	Moccasin
Scalinata	Foot-related	9	4	1.93	Staircase
Ciabatta	Foot-related	8	3	0.20	Slipper
Tattica	Abstract	7	3	5.82	Tactics
Superbia	Abstract	8	3	0.77	Arrogance
Ritegno	Abstract	7	3	0.45	Reluctance
Elogio	Abstract	6	3	2.40	Praise
Deferenza	Abstract	9	4	0.30	Deference
Gelosia	Abstract	7	4	10.43	Jealousy
Lusinga	Abstract	7	3	0.11	Allurement
Inganno	Abstract	7	3	6.08	Deceit

English translations are given in the final column

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