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When nominal features are marked on verbs: A transcranial magnetic stimulation study

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Abstract

It has been claimed that verb processing (as opposed to noun processing) is subserved by specific neural circuits in the left prefrontal cortex. In this study, we took advantage of the unusual grammatical characteristics of clitic pronouns in Italian (*e.g.*, *lo* and *la* in *portalo* and *portala* 'bring it [masculine]/[feminine]', respectively)—the fact that clitics have both nominal and verbal characteristics, to explore the neural correlates of verb and clitic processing. We used repetitive transcranial magnetic stimulation (rTMS) to suppress the excitability of the left prefrontal cortex and to assess its role in producing verb+det+noun and verb+clitic phrases. Results showed an interference effect for both kinds of phrases when stimulation was applied to the left but not to the right prefrontal cortex. However, the interference effect was significantly greater for the verb+clitic than for the verb+det+noun phrases. These findings support the view that clitics increase the morphosyntactic complexity of verbs.

Keywords: rTMS; Verb morphosyntax; Clitics; Left prefrontal cortex

1. Introduction

Neuropsychological research on the neural basis of grammatical class knowledge suggests that nouns and verbs are subserved by distinct neural mechanisms. There is ongoing debate in the literature on whether these observations reflect truly grammatical distinctions or are simply a byproduct of the kinds of meaning associated with prototypical nouns (objects) and verbs (actions). Crucially, however, there are a number of studies showing dissociations between Nouns and Verbs that were closely matched on semantic dimensions (Berndt & Haendiges, 2000; Caramazza & Hillis, 1991; Damasio & Tranel, 1993; Laiacona & Caramazza, 2004; Shapiro, Shelton, & Caramazza, 2000). These findings have been interpreted as support for the grammatical account, thus setting the stage for a thorough investigation with new methodologies.

Some electrophysiological studies of verb and noun perception have shown increased left-lateralized anterior positivity for verbs (Deahene, 1995; Federmeier, Segal, Lombrozo, & Kutas, 2000). Studies using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have demonstrated that left prefrontal and medial frontal cortex are recruited in verb processing tasks (Perani et al., 1999; Petersen, Fox, Posner, Mintum, & Raichle, 1988, 1989; Raichle et al., 1994; Shapiro, Moo, & Caramazza, 2006; Shapiro et al., 2005; Tyler, Bright, Fletcher, & Stamatakis, 2004).

Imaging investigations do not, however, unequivocally support a grammatical account of noun/verb differences. On the one hand, functional neuroimaging has so far failed, with a few exceptions (*e.g.*, Shapiro et al., 2005), to reveal anatomically distinct patterns of activation for

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nouns and verbs using either word generation paradigms (Warburton et al., 1996) or lexical decision tasks (Fujimaki et al. (1999); Perani et al., 1999). On the other hand, some recent imaging studies have reported minimal—if any—word-class specificity effects in the context of extensive effects of semantic dimensions (*e.g.*, Saccuman et al., 2006; Sörös, Cornelissen, Laine, & Salmelin, 2003; Tyler, Russell, Fadili, & Moss, 2001; Tyler et al., 2003; Vigliocco et al., 2006). A possible reason for this pattern may be that in none of these studies was verb morphosyntax directly and explicitly involved, and in a few cases (*e.g.*, Tyler et al., 2001, 2003) the focus explicitly was on semantic dimensions—a semantic categorization task was used.

Thus, one possibility is that the experimental paradigms that have been used led to an underestimation of the importance of the word-class effect. Indeed, it has been suggested that the type of task may modulate the probability of obtaining grammatical effects (Tyler et al., 2004). Those authors reported a verb-specific activation in the left inferior frontal gyrus when regularly inflected nouns and verbs were contrasted, a result they attributed to differences in the morphosyntactic characteristics of the two categories.

This hypothesis is explicitly concerned with inflectional morphology (*i.e.*, morphological operations within an inflectional paradigm) and does not make any commitment on derivational morphology. In the latter case, results may be different (*e.g.*, Siri et al., 2007). The paper by Siri et al. (2007) is also relevant in that it calls into question the general view of neural segregation between Nouns and Verbs.

The authors asked Italian speakers to name pictures of events using either an infinitive verb (*correre* 'to run'), an inflected verb (*corre* '[he/she] run') or a deverbal noun (*i.e.*, a noun derived from a verb, *corsa* '[the] run'). All the experimental conditions produced activations in the left inferior frontal gyrus (IFG), but they differed with respect to the amount of activation produced as follows: the least activation was reported for the production of an infinitive verb, intermediate activation for the production of an inflected verb and greatest activation for the production of deverbal nouns. These data were interpreted as showing that there is no neural distinction depending on the N/V status; rather, both verb and noun morphosyntax would be subserved by the same neural circuit. This conclusion is, however, unwarranted in the face of the data. This is because deverbal nouns do not represent a pure case of noun morphosyntax as they involve verb morphosyntax as well—they come from verbs. Thus, there is the possibility that the activation for deverbal nouns reflects the transformation from the base verb rather than noun production *per se*. The greatest activation in this condition could be due to the fact that the task on the verb is more difficult with respect to the other conditions (the transformation is outside the verbal paradigm, and, as acknowledged by the authors themselves, deverbal nouns are less frequent and less favourite alternatives as pictures' name). Therefore, an alternative and plausible reading of the results reported by Siri et al. (2007) is that the amount of left IFG activation is modulated by the morphological processing required *on the verb*, thus maintaining the view of a grammatical distinction between Nouns and Verbs at the neural level.

There are a few repetitive transcranial magnetic stimulation (rTMS) studies that lend support to the latter view (Cappelletti, Fregni, Shapiro, Pascual-Leone, & Caramazza, in press; Shapiro, Pascual-Leone, Mottaghy, Gangitano, & Caramazza, 2001). These authors reported interference specific for verbs as opposed to nouns following inhibitory stimulation of the left prefrontal cortex. Importantly, this effect was obtained when participants had to produce nouns and verbs in a morphological alternation task (*e.g.*, 'a car'/'some cars', 'they jump'/'he jumps').

This pattern is in line with the observation that rTMS to the left prefrontal cortex is able to facilitate action- as opposed to object-naming when a facilitatory (*vs.* inhibitory) rTMS interval is used (Cappa, Sandrini, Rossini, Sosta, & Miniussi, 2002). Remarkably, the effect obtains in a task (picture naming) that does not explicitly involve morphosyntactic aspects of noun and verb processing.

This pattern is also in line with the evidence coming from imaging studies, in that the most consistent evidence of distinct neural substrates for different grammatical classes has come from studies showing verb-specific activation in different parts of the left frontal lobe (Perani et al., 1999; Shapiro et al., 2005; Tyler et al., 2004).

One of the major advantages of the rTMS technique is that it demonstrates not only that a brain region is active during the performance of a given task but that the area is actually necessary for the task being performed (Walsh & Rushworth, 1999). When applied at low-frequency (1 Hz), rTMS temporarily interferes with cognitive processing beyond the duration of a train of pulses (Pascual-Leone, Walsh, & Rothwell, 2000).

Shapiro et al. (2001; see also Cappelletti et al. (in press)) found that, following low-frequency rTMS targeted to a portion of the left prefrontal cortex along the midfrontal gyrus anterior and superior to Broca's area, both verb and pseudo-verb production was significantly impaired, whereas noun and pseudo-noun production was unaffected.

The participants' task was to produce singular or plural noun forms (*e.g.*, 'a car'/'some cars') and 3rd person singular or plural verb forms (*e.g.*, 'they jump'/'he jumps') in response to specific cues. The fact that the morphological operation always involved the same kind of phonological material (add or subtract /s/), ruled out any explanation in terms of phonological differences between verbs and nouns. Furthermore, the fact that the same pattern of results was obtained for real words and pseudo-words (*e.g.*, 'a wug'/'some wugs'; 'they wug'/'he wugs') suggests that the left prefrontal cortex is sensitive to the grammatical properties of nouns and verbs independently of other conceptual-semantic properties that may be correlated with words of different grammatical classes.

The objective of the current study was to extend the research on the neural correlates of grammatical category to a special class of unstressed pronouns, widespread in Romance languages, called clitics (*e.g.*, in Italian, *lo* and *la* in *portalo* and *portala* 'bring it [mas]/[fem]!', respectively).

Although clitics have nominal referents and are specified for nominal features (*e.g.*, gender), they attach to verbs and depend phonologically and syntactically on verbs.

Italian clitics can precede (*i.e.*, they are proclitics) or follow (*i.e.*, they are enclitics) the verb (cf. *lo porto* 'I bring it [mas]' *vs. portalo* 'bring it [mas]!'), depending on the verb form—enclisis is used for non-finite forms and imperative, whereas proclisis is used for the other forms. In enclisis, the clitic and the verb are combined into one word, with the clitic forming a kind of affix. In this study, only enclitics were used (*e.g.*, *portalo* 'bring it [mas]'; see Finocchiaro & Caramazza, 2006).

In standard Italian, pronominal clitics do not change a verb's stress pattern (*e.g.*, *pórta* 'bring!' and *pórtalo* 'bring it'[mas]; *pórto* 'I bring' and *lo pórto* 'I bring it [mas]') and cannot be used with the function of grammatical subjects (subject pronouns are always full pronouns in standard Italian). This is the reason why clitics with the grammatical function of direct objects (accusative) were used here.

In essence, clitics are pronouns, and, as the other personal pronouns, they need conceptual-semantic and grammatical information about their noun referents (*e.g.*, gender, number, and case features). However, because of their connection to verbs—due to their phonological and syntactic characteristics, at some processing stage they must be combined with the verb. Linguists have located the formation of the verb–clitic cluster at different levels: lexical (*e.g.*, Crysmann, 2000; Monachesi, 1999) or phrasal (*i.e.*, syntactic, *e.g.*, Belletti, 1999; Kayne, 1991; Uriagereka, 1995).

The lexicalist view holds that clitics are affix-like elements. Therefore, the verb–clitic relation is exactly parallel to the verbal base-verbal affix relation, in that neither clitics nor verbal affixes are supposed to fill an argument position. Instead, both of them would attach to the verb in the lexicon. The syntactic approach assumes that the object clitic is generated in argument position. Then, according to one of the most influential analyses (*e.g.*, Kayne, 1991), the clitic left-adjoins to a functional head, yielding the clitic–Verb order in cases where the functional head dominates the verb. (The Verb–clitic order in Italian is thought to result from the verb's having moved leftward past the functional head to which the clitic has adjoined.) The crucial point here is that on both the lexicalist and the syntactic accounts the clitic increases the morphosyntactic complexity of the verb to which it attaches.

In the present study, we asked whether the circuits dedicated to the processing of verb morphosyntax are also involved in processing their clitic hosts. Thus, we are not interested either in the Noun/Verb distinction *per se* or in the conditions/limits that restrict the possibility of observing this distinction thus allowing to speak of grammatical class effects. Rather, we used the morphosyntactic part of the Noun/Verb distinction as a ground on which our main focus—clitic processing, is built. This choice is motivated by the robust evidence (see above) showing that verb inflectional morphology—at least when it is directly focussed on—maps onto a partially different brain circuit with respect to noun inflectional morphology.

We used low-frequency rTMS in order to transiently disrupt the normal functioning of the same portion of the left prefrontal cortex targeted in Shapiro et al. (2001).

We compared the production of verbs in two different conditions: (1) verb+clitic phrases and (2) verb+det+noun phrases, in response to the same set of stimuli.

Repetitive TMS was applied to the left (L) targeted area and to its right (R) homologue as a control (see Cappelletti et al. (in press)).

On each trial, participants were presented with a given verb (*e.g.*, *guardare* 'to look at') and, immediately after, with the picture of an object. Their task was to inflect the verb in the 2nd person singular form of the imperative (*e.g.*, *guarda* 'look at') and, depending on the experimental condition, to follow it with either the appropriate object clitic pronoun (*lo* 'it' [m] or *la* 'it' [f]—condition 1) or the appropriate determiner and noun (*e.g.*, *guarda il tavolo* 'look at the table'—condition 2).[1] The response was to be given upon the presentation of the picture.

The task was performed before and after the application of L- or R-rTMS. We reasoned that, since verb processing is necessarily required in both tasks, L-rTMS should interfere for both conditions relative to R-rTMS.

In addition, if the presence of a clitic increases the morphosyntactic complexity of the verb, it would also increase—exactly like the presence of a verbal affix—the involvement of the brain region devoted to verb morphosyntax. Thus, participants are expected to be slower, following L-rTMS, in the condition verb + clitic as opposed to the condition verb+det+noun.[2]

If, on the other hand, the complexity of clitics is limited only to their syntactic function, no difference between verb+det+noun and verb+clitic phrases is predicted after rTMS disruption. This is because the syntactic relation between a verb and its direct object is independent from the grammatical category of the object itself (noun, pro-

[1] It should be remarked that clitics are very commonly used in oral as well as in written language, so that their production may be considered a natural task for Italian participants.

[2] Since participants perform the experimental task with the same stimuli both before and after application of rTMS, we expect a certain amount of facilitation due to a learning effect for the second presentation of the task. That is, after the application of rTMS (see Shapiro et al., 2001). Thus, the crucial question is whether the amount of facilitation due to learning is reduced after L-rTMS as compared to the condition after R-rTMS. It is generally assumed that, by subtracting the facilitation effect post-R-rTMS to the facilitation effect post-L-rTMS, one gets a measure of the interference due to left rTMS.

noun). In this case, no difference in RTs is expected as a function of experimental condition.

The stimulation of the right hemisphere served as a control for the left hemisphere, and sham stimulation—a condition of simulated stimulation, with the coil angled 90° on the edge of a single wing so that the magnetic field does not penetrate the cortex, was not included. This choice capitalizes on the observation that, when both SHAM and a control site are used as controls, they give rise to comparable results (*e.g.*, Fierro et al. (2000) on contralateral neglect, and Cappelletti et al. (in press) for a linguistic task directly relevant to the issue addressed here). Indeed, it has also been claimed that having a control site is a better control than having SHAM stimulation (*e.g.*, Burt, Lisanby, & Sackeim, 2002). One of the main reasons is that whereas SHAM stimulation controls for effects that *are not related to TMS in general*, stimulation of a control site controls for effects that *are not related to TMS on a specific brain area*.

We also included an additional task (simple picture naming) in order to replicate the finding that the left anterior midfrontal gyrus is not selectively involved in Noun processing. As in the case of the Verb Phrase production task, picture naming was performed before and after L- and R-rTMS. We did not, however, directly compare participants' performance on Picture Naming and VP production tasks.

To anticipate the results, it was found that L-rTMS—but not R-rTMS—interfered with the production of both verb+clitic and verb+det+noun phrases, but the magnitude of interference was significantly stronger for the verb+clitic task. As expected, no difference that could be attributable to rTMS was observed for the picture naming task.

2. Methods

2.1. Participants

Eleven right-handed native Italian speakers (ages 22–38) volunteered for the experiment. All participants were healthy and had no history of neurological or psychiatric illness. The study was approved by the local ethical committee. Participants were instructed on experimental conditions and techniques, and they gave their informed consent before participating to the study.

2.2. Materials

Ninety black-and-white pictures of objects were selected: fifty pictures for the Verb Phrase (VP) production task; forty for the picture naming task (see Appendix A). Picture names were controlled for length and frequency as reported in a corpus of Italian written language of 1.5 million tokens (Corpus di Italiano Contemporaneo, 1989). For the VP production task, mean picture name frequency was 68, mean letter length was 6.1, mean syllable length was 2.6. For the naming task, mean name frequency was 56, mean letter length was 7; mean syllable length was 2.7. Twelve additional pictures were used as practice trials at the beginning of the picture naming task, and twenty at the beginning of the VP production task.

Five verbs were selected. Each verb was paired with ten pictures.

Stimulus presentation was randomized for each participant. Particular care was taken to avoid semantic, phonological, or associative relations between consecutive trials.

2.3. Procedure

Subjects were seated comfortably on a chair at reading distance in front of a computer screen. Each subject participated in two sessions separated by at least one week. In the first session, rTMS was applied to the targeted area to only one hemisphere and to the other hemisphere in the second session. The procedure for each session was the same: participants were first familiarized with all the pictures; they then named a set of 40 pictures both before and after rTMS application. They rested for half an hour, and then did the VP production task before and after another rTMS application. The stimuli used for each task were the same for the conditions pre- and post-rTMS in both sessions.

2.4. Familiarization phase

During the picture familiarization phase, pictures were presented one at a time. For each item, a fixation cross first appeared for 500 ms, followed by a picture for 2000 ms, with the object's name appearing beneath the picture for the final 1500 ms. All participants were asked to name the picture aloud upon seeing its name. The next trial initiated after 800 ms.

2.5. Picture naming task

In this part of the experiment, all participants named pictures without word prompts. Twelve practice trials preceded the set. For each item, a fixation cross appeared for 500 ms and was immediately followed by the picture. The participant was to name the picture. The picture disappeared as soon as participants responded, or after 2000 ms. have elapsed, whichever came first. The inter-trial interval was fixed at 2000 ms. After one block of picture naming, 600 pulses of 1 Hz rTMS were applied to the left or right hemisphere of the participant, and the naming task was repeated. Participants then rested for half an hour, after which they began the phrase production task.

RTs were recorded by means of a voice-key from the onset of the picture. Stimulus presentation was controlled by the program Psyscope (Cohen, Mac Whinney, Flatt, & Provost, 1993). Instructions emphasised response speed and accuracy. The experimenter recorded the errors manually.

2.6. VP production task

Twenty practice trials preceded the experimental trials. For each trial, a fixation cross appeared on the screen for 500 ms, followed by the infinitive form of a verb (*e.g.*, *guardare* 'to look at') for 250 ms, and then by a picture of an object. Participants were instructed to inflect the verb in the second person singular of the imperative (*e.g.*, *guarda* 'look at') and, depending on the experimental condition, to follow it with either the appropriate object clitic pronoun (*e.g.*, *guardalo* 'it' [m] or *guardala* 'it' [f]—condition 1) or the appropriate determiner and noun (*e.g.*, *guarda il tavolo* 'look at the table'—condition 2). Participants were randomly assigned to condition 1 ($N = 6$) or condition 2 ($N = 5$). The picture disappeared as soon as participants responded, or after 2000 ms. have elapsed, whichever came first. Verbs were presented in capital letters in 32-point Arial font. The inter-trial interval was fixed at 2500 ms.

Six-hundred pulses of 1 Hz rTMS were then applied to the same hemisphere stimulated for the naming task in a given session, and the phrase production task was repeated. RTs and errors were recorded as for the picture naming task.

2.7. Application of rTMS

Magnetic stimulation was delivered by a Cadwell high-frequency magnetic stimulator equipped with a water-cooled figure-of-eight coil (each loop 4.5 cm in diameter). In each experimental session, two trains of 600 pulses were delivered at 1 Hz frequency and 100% of the motor threshold. Motor threshold (MT) was determined for each subject as the minimum stimulus intensity able to elicit in 5 or more of ten consecutive stimulations a motor evoked potential (MEP) of at least 50 μV in contralateral first dorsal interosseous muscle. Mean motor threshold was 47.7 ± 5.8 of the maximum stimulator output.

Based on a previous study by Shapiro et al. (2001), the scalp stimulation site in each subject was 6 cm anterior and 1 cm ventral to the motor spot for the first dorsal interosseous muscle. An important limitation of our study was that we did not use a neuro-navigation system to localize the stimulation site. However, the coil position, previously checked on normal subjects by MRI (Shapiro et al., 2001) was assumed to target an inferior portion of the midfrontal gyrus of the left hemisphere just anterior and superior to Broca's area.

This site was marked on tightly fitting Lycra caps worn by subjects in order to maintain the coil position constant during the experiment. The stimulation coil rested tangentially on the subject's scalp. During stimulation, subjects sat comfortably in a chair. The order of hemisphere stimulation was randomized across participants.

2.8. Statistical analysis

The following responses were scored as errors and excluded from the analysis of latencies: responses that differed from the targets, failures to respond, failures of the recording equipment, RTs above 2000 ms and below 300 ms, and RTs exceeding each participant's mean by more than 3 *SD*. A repeated-measure ANOVA was performed on the reaction time differences (Δ) between pre-rTMS performance and post-rTMS performance for each hemisphere. The same procedure was followed for the VP production task and the naming task.

For the VP production task, there were two variables, each with two levels: *Condition* (verb+clitic *vs.* verb+det+noun), and *Site* (left *vs.* right). Condition was treated as a between-subjects variable; Site was treated as a within-subject variable. Only the variable *Site* was considered for the picture naming task. The same statistical analysis was performed with participants' errors as dependent measures.

3. Results

3.1. VP production task

Discarded data accounted for 3.8% of the verb+clitic condition (4.5% and 3.2% before and after stimulation, respectively) and for 4.8% of the verb+det+noun condition (5.4% and 4.2% before and after stimulation, respectively). No significant effects emerged from the error analysis.

Analysis of response latencies revealed a main effect of Site ($F(1, 548) = 23$, $p < .001$), showing that subjects had a lower level of repetition priming after left rTMS (599 ms [SE 41] *vs.* 549 ms [SE 32], $\Delta = 50$ ms [SE 10]) than after right rTMS (618 ms [SE 40] *vs.* 531 ms [SE 31], $\Delta = 88$ ms [SE 17]). There was also an interaction of Condition × Site ($F(1, 548) = 4$, $p = .04$).

Duncan post hoc analyses showed that the difference between right and left stimulation was significant for both the verb+clitic (right, $\Delta = 88$ ms [SE 31] *vs.* left, $\Delta = 37$ ms [SE 5], $p < .001$) and the verb+det+noun conditions (right, $\Delta = 87$ ms [SE 12] *vs.* left, $\Delta = 65$ ms [SE 21], $p < .05$). In addition, the reaction time differences (Δ) between pre-rTMS performance and post-rTMS performance were the same for both conditions when rTMS was delivered to the right hemisphere ($p = .9$), but not when rTMS was delivered to the left hemisphere ($p = .046$.). The latter finding shows that left rTMS—as opposed to right rTMS—significantly reduced the learning effect in both conditions. However, the magnitude of the interference was greater for the verb+clitic condition than the verb+det+noun condition (see Fig. 1).

3.2. Picture naming task

Discarded data accounted for 5.9% before TMS and for 4.5% after the TMS treatment. Error rates did not differ depending on Site. No significant difference emerged from the analysis of RTs, since the amount of facilitation was unaffected by the site of stimulation (31.5 ms, SE 6.7 (right) *vs.* 39.7 ms, SE 8 (left); $F(1, 439) = .7$, $p = .4$).

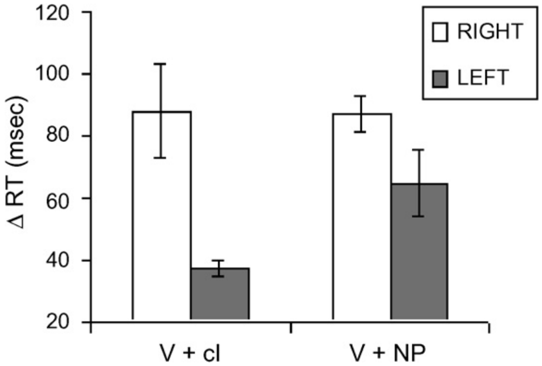

Fig. 1. Effects of left and right rTMS on production of verb+clitic and verb+det+noun phrases. Error bars depict standard errors of the means.

4. Discussion

Our results support the view that the left prefrontal cortex plays a crucial role in processing verb morphosyntax. It is well known that the repetition of production tasks with a limited set of stimuli causes a robust decrease in response latency over time. Our results show that rTMS applied to the left prefrontal cortex substantially reduces the magnitude of this learning effect for verb production. When participants had to name pictures (that is, when they simply produced nouns), there was no difference in repetition priming following left and right rTMS.

Unlike Shapiro et al. (2001), verb morphology was not directly manipulated in this study. The same verb form was produced in every trial in response to the infinitive form stimulus. It is quite interesting that even such a simple morphological operation is sufficient to show selective involvement of the left prefrontal cortex in verb production.

This study is original in showing the differential effects of left rTMS on the production of verb+det+noun and verb+clitic phrases. After right rTMS, equal amounts of repetition facilitation were found in both conditions. After left rTMS, significantly reduced repetition facilitation effects were observed for both conditions. Crucially, however, this reduction is significantly greater for the verb+clitic than the verb+det+noun phrase condition. This finding can be attributed to the special status of clitics: although clitics have nominal referents, they are phonologically and syntactically dependent on the verb. This dependency is particularly strong in the case of enclitics (Benincà & Cinque, 1993), as they are orthographically attached to verbs. We conjecture that (en)clitics may increase the morphosyntactic complexity of the verb—indeed, clitics seem to be treated as verbal affixes rather than as nominal particles.

Of course, this is not to deny that clitics function syntactically as direct objects. However, this syntactic function is not responsible for the differential patterns of rTMS effects found for the verb+clitic *vs.* verb+det+noun conditions, for otherwise the interference from left rTMS should have been the same for verb+clitic and verb+det+noun phrases—clitics and nouns are both used as direct objects in this study.

Alternatively, one may want to appeal to a phonological explanation of the clitic results. According to this account, left rTMS could be disrupting the phonological processes associated with the verb–clitic integration. In this case, our results would not speak either to the morphological aspects of cliticization or to the difference between the neural correlates of verb and noun morphosyntax.

This hypothesis receives some support by the observation that, as revealed by a number of fMRI studies (*e.g.*, Demonet et al., 1992; Fiez et al., 1995; Heim, Opitz, Müller, & Friederici, 2003; Zatorre, Evans, Meyer, & Gjedde, 1992), regions overlapping with or adjacent to the area targeted in this study are associated with phonological processes.

However, other rTMS studies were able to show that the left brain area stimulated in this study—the inferior portion of the midfrontal gyrus just anterior and superior to Broca's area—is necessary for verb morphosyntax independently from phonology. Thus, Shapiro et al. (2001) found that the application of rTMS to this brain area interfered with verb and pseudo-verb production but not with noun and pseudo-noun production. Since their task always involved the same kind of phonological material (add or subtract/s/) independently of the grammatical class of the given stimulus, a phonological account of the results is not plausible. In a similar vein, Cappelletti et al. (in press) found that this area is necessary for both regular and irregular verb morphosyntax, despite the undeniable phonological differences between a given verb stem with regular and irregular forms, respectively. Hence, the most straightforward view seems to be that the effects of rTMS on clitic production do indeed reveal processing of the morphosynatx of verb–clitic clusters.

An important caveat concerns the extent to which the rTMS results reported on speak to the phonological processes of clitic clusterization. Clitics form a single unit with the host verb at various levels of analysis—phonological, morphological, syntactic. This aspect is not captured either by the comparison between regular and irregular verb morphology or by the comparison between phonologically identical nouns and verbs. Indeed, there is some evidence showing that a phonological process such as syllabification, may recruit prefrontal areas including Broca's area (see Indefrey & Levelt, 2004). But, again, it is not clear the extent to which clitic clusterization may be assimilated to resyllabification in the light of the fact that, in standard Italian, the clitic does not change the verb syllabification, it simply attaches to the verb. Thus, it is a matter for future research to investigate the possible similarities between the formation of clitic clusters and resyllabification processes in functional or neural terms. At the same time, it might be challenging to try to disentangle the relative impact of phonological and morphosyntactic components in the verb–clitic relation. Indeed, the phonological characteristics of clitics may have contributed to the observed pattern. At the moment, we think that it would be difficult to appeal only to the pure phonological part of cliticization as a thorough explanation of the data. Indeed, this would be tantamount to saying that the left prefrontal cortex is sensitive to the phonological side of the operation of adding a syllable to a word (a very difficult control to do, since the adjunction of a syllable to a word always involves a morphological component).

Another alternative explanation can be formulated in terms of differences in the semantic content of clitic phrases and noun phrases. It could be argued that the differential patterns of performance between the verb+clitic and verb+det+noun conditions reflect the different semantic content of clitics and nouns. One could argue that a fully specified noun engages a much more extensive neural network than a clitic. Indeed, a few fMRI studies with normals have shown that the left inferior prefrontal cortex plays a role in semantic processing. However, as underscored by these studies, the semantic role of this area is specifically relevant for the selection of competing semantic knowledge (Gabrieli, Poldrake, & Desmond, 1998; Gold & Buckner, 2002). On this view, the production of verb+det+noun *vs.* verb+clitic phrases would not be expected to lead to different outcomes following rTMS of the anterior portion of the left midfrontal gyrus.

Besides, it must be noted that input conditions were the same for both the verb+clitic and verb+det+noun phrases. Participants had to extract the same type of semantic information from a given picture independently of the response format. Moreover, the information needed for the selection of the grammatical features for the NP and the clitic is the same in the two cases.

These considerations receive additional support from those linguistic analyses that draw a parallel between the function of situationally salient definite NPs and deictic pronouns (*e.g.*, von Heusinger, 2002). Accordingly, both clitics and NPs would be functionally equivalent in our experimental context, in that they both denote a contextually salient object (*i.e.*, the pictured object) in the response to be produced.

Our results could also be compatible with a syntactic account based on grammatical class differences between nouns and pronouns. On this view, the pattern of effects observed here should be attributed to processing differences between grammatical categories (pronouns *vs.* nouns) rather than to differences in verb processing. The reasoning would be that the neural substrates for pronoun and verb processing overlap more than the neural substrates for noun and verb processing. Although this hypothesis cannot be easily dismissed, it must be noted that clitic production was compared to determiner+noun production, and not to bare noun production. Crucially, clitics—as well as the corresponding strong pronouns—and articles both require grammatical information about the noun's number and gender.

Follow-up research with similar experimental designs as the one used here could help discriminate between the grammatical category and the morphosyntactic accounts. For example, it would be interesting to compare the behavior of strong pronouns (*e.g.*, demonstratives such as *questo/questa* 'this [mas.]/this [fem.]' and *quello/quella* 'that [mas.]/that [fem.]') with enclitics. Leaving aside the semantic differences between third person personal pronouns and demonstratives (*e.g.*, Bhat, 2004), different predictions follow from the grammatical class and the morphosyntactic accounts. According to the grammatical class account, demonstratives should pattern with enclitics as they are both members of the class of pronouns. On the other hand, according to the morphosyntactic account, demonstratives should pattern differently from enclitics, since they do not form a morphological unit with the verb as is the case for enclitics.

Until independent evidence is available on the neural correlates of grammatical classes other than nouns and verbs, the most straightforward interpretation of our data is that the differential effect of left rTMS on the production of verb+clitic and verb+det+noun phrases is to be attributed to the peculiar relation between verbs and clitics.

We have shown that when nominal features attach to verbs, they are processed, in part, by the same neural circuits that are involved in processing verb morphosyntax.

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Appendix A. Materials used in the experiment

A.1. VP production task

A.1.1. Feminine pictures

banana 'banana', macchina 'car', pistola 'gun', tenda 'tent', zucca 'pumpkin', chiesa 'church', farfalla 'butterfly', piramide 'pyramid', sirena 'siren', tromba 'trumpet', chitarra 'guitar', croce 'cross', ruota 'wheel', sedia 'chair', sella 'saddle', carota 'carrot', chiave 'key', mucca 'cow', racchetta 'racket', scala 'ladder', foca 'seal', giraffa 'giraffe', pera 'pear', scarpa 'shoe', scopa 'broom'.

A.1.2. Masculine pictures

giornale 'newspaper', letto 'bed', libro 'book', rossetto 'lipstick', serpente 'snake', albero 'tree', calendario 'calendar', dado 'dice', orologio 'watch', sole 'sun', anello 'ring', birillo 'skittle', carciofo 'artichoke', cubo 'cube', imbuto 'funnel', cappello 'hat', fungo 'mushroom', osso 'bone', timone 'helm', topo 'mouse', leone 'lion', ombrello 'umbrella', pettine 'comb', piatto 'plate', scheletro 'skeleton'.

A.1.3. Verbs

comprare 'to buy', guardare 'to look at', portare 'to bring', prendere 'to take', trovare 'to find'.

A.2. Picture naming task

A.2.1. Feminine pictures

carriola 'wheelchair', ciliegia 'cherry', lumaca 'snail', siringa 'syringe', scimmia 'monkey', spazzola 'brush', sciarpa 'scarf', matita 'pencil', panchina 'bench', tigre 'tiger', ballerina 'dancer', maschera 'mask', gabbia 'cage', spada 'sword', colonna 'column', porta 'door', bomba 'bomb', pipa 'pipe', pianta 'plant', campana 'bell'.

A.2.2. Masculine pictures

vaso 'vase', fucile 'rifle', disco 'disc', coltello 'knife', telefono 'telephone', piede 'foot', treno 'train', braccio 'arm', occhio 'eye', pinguino 'penguin', tagliere 'chopping board', tubo 'tube', portafoglio 'wallet', ananas 'pineapple', biberon 'feeding bottle', semaforo 'traffic-light', aquilone 'kite', tamburo 'drum', lucchetto 'padlock', ventaglio 'fan'.

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