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The role of the prefrontal cortex in sentence comprehension: An rTMS study

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ABSTRACT

Using repetitive transcranial magnetic stimulation (rTMS), we investigated the role of the left and right dorsolateral prefrontal cortex (DLPFC) in sentence comprehension. Subjects were required to judge which of the two pictures correctly matched the meaning of active and passive semantically reversible sentences (subject–verb–object); the incorrect picture did not match the sentence in term of lexical items (semantic task) or agent–patient structure (syntactic task). The subjects performed the task while a series of magnetic stimuli were applied to the left or right DLPFC. When rTMS was applied to the left DLPFC, the subjects' performance was delayed only for the semantic task, while rTMS applied to the right DLPFC slowed the processing of syntactic information. The results of this experiment provide direct evidence of a double dissociation between the rTMS effects and the type of task, which may reflect a differential hemispheric involvement of working memory (WM) resources during sentence comprehension.

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1. Introduction

The deceptively simple act of understanding the meaning of a common sentence requires a number of cognitive processes. Minimally, these include the analysis of its phonological and syntactic structure, as well as of the meaning of the composing lexical items. Sentence comprehension requires processing a sequence of words, and analyzing their syntactic and thematic organization in order to create a correct representation

of the entire sentence. This elaboration needs to maintain in an activated state both single word meaning and the syntactic relations between words (Just and Carpenter, 1992). While current models of language comprehension make different predictions on the proposed time course of syntactic and semantic integration, there is general agreement about the fact that these processes require the temporary storage and manipulation of multiple classes of information (Friederici and Kotz, 2003). Both storage and manipulation are thought

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115 to depend upon working memory (WM) resources. Behavioural
116 experiments indicate that the comprehension of syntactically
117 complex sentences is a demanding process, often entailing
118 a high memory load (Turkstra and Holland, 1998; Stromswold
119 et al., 1996; Stowe et al., 1998).

120 The neural mechanisms involved in sentence comprehen-
121 sion have been investigated by means of lesion studies and
122 of functional neuroimaging. While patient studies have
123 emphasised the role of damage to perisylvian areas of the
124 left hemisphere in sentence comprehension disorders (Caplan
125 et al., 1996), to ascribe specific functions to discrete regions
126 within this network has proven difficult. The left ventral pre-
127 frontal cortex, in particular Broca's area, has traditionally
128 been considered to play a central role in syntactic processing
129 (see Grodzinsky and Amunts, 2006, for a comprehensive dis-
130 cussion). Imaging studies have provided further evidence for
131 a central role of Broca's area in syntactic processing (Dapretto
132 and Bookheimer, 1999; Heim et al., 2003; Moro et al., 2001;
133 Caplan et al., 1998, 1999, 2000). During online sentence com-
134 prehension, Broca's area is important not only for syntactic in-
135 tegration, but also for WM mechanisms relevant for language
136 processing (Fiebach et al., 2005). The two factors of syntactic
137 complexity and sentence length have been often confounded
138 in the imaging literature. Some investigations have supported
139 the view that the inferior frontal gyrus activation is specific for
140 syntactic processing, while the engagement of the dorsolateral
141 prefrontal cortex (DLPFC) may reflect the WM load (Caplan et al.,
142 2002; Hashimoto and Sakai, 2002; Walsh and Rushworth, 1999;
143 Martin et al., 2004). A recent fMRI study, which analyzed the
144 areas involved in a sentence judgment task, has underlined
145 the recruitment of the dorsal portion of left frontal cortex. Spe-
146 cifically, this area is involved during the processing of syntactic
147 violations associated to a large WM load (Cooke et al., 2006).

148 It must also be underlined that language comprehension
149 does not involve only the left hemisphere. Less extensive acti-
150 vations have also been observed in right prefrontal cortex dur-
151 ing sentence comprehension (Wartenburger et al., 2004; Moro
152 et al., 2001; Just et al., 1996). This finding may suggest a quanti-
153 tative change of the activation of prefrontal cortex due to
154 a more demanding task (Just et al., 1996) or an engagement of
155 other processing operations, such as visual WM resources, in
156 order to solve a more complex task (Rapp and McCloskey, 1997).

157 Transcranial magnetic stimulation (TMS), a technique that
158 can be used to map the flow of information across different
159 brain regions during the execution of a cognitive task (Walsh
160 and Rushworth, 1999), is another tool which can be applied
161 to the investigation of the neural mechanisms responsible
162 for sentence comprehension. Only one study has investigated
163 the effects of TMS on syntactic processing (Sakai et al., 2002).
164 In that study, a double pulse TMS was delivered to the left in-
165 ferior frontal gyrus or the left middle frontal gyrus, using three
166 possible timings (0, 150, 350 msec after target onset) during
167 a syntactic or semantic decision task. The main finding was
168 that during syntactic decisions there was a shortening of reac-
169 tion times, but only when TMS was applied to the left inferior
170 frontal gyrus 150 msec after target onset. There is limited ad-
171 ditional TMS evidence for a functional role of the prefrontal
cortex in language processing. A recent study highlighted
a functional dissociation in left inferior frontal cortex (LIFC),
with rTMS on posterior LIFC slowing homophone judgments,

172 while anterior LIFC slowed synonym judgments (Gough
173 et al., 2005). An involvement of left lateral prefrontal cortex
174 in lexical-semantic processing was demonstrated using
175 rTMS (Cappa et al., 2002; Devlin et al., 2003).

176 More extensive evidence is available that repetitive TMS
177 (rTMS) applied to the prefrontal cortex can interfere with WM
178 tasks. With a few exceptions (Hautzel et al., 2002), most studies
179 support a relationship between, respectively, verbal and visual
180 stimuli, and left and right prefrontal cortex (Manoach et al.,
181 2004; Wendt and Risberg, 2001; Johnson et al., 2003). The activa-
182 tion of BA 46 observed during WM task is lateralized, with a left
183 activation for verbal stimuli and a right activation for visual
184 stimuli (Leung et al., 2002; Rowe and Passingham, 2001; Van
185 der Linden et al., 1999; Stern et al., 2000).

186 A further functional distinction can be found between the
187 dorsal and the ventral prefrontal cortex within each hemi-
188 sphere (Sala et al., 2003). There is some evidence that the
189 left ventral prefrontal cortex is more relevant for verbal WM,
190 whereas right dorsal prefrontal cortex is more important for
191 the spatial WM (Walter et al., 2003). Recent TMS studies
192 showed that verbal WM is dependent on normal functioning
193 of the middle frontal gyrus bilaterally, suggesting that right
194 and left-sided areas might be involved in parallel processing
195 of different features of stimuli (Mottaghy et al., 2002a, 2003).
196 Moreover the same authors, in a different experiment,
197 showed that the stimulation of the DLPFC impairs perfor-
198 mance in spatial as well as non-spatial tasks. At the same
199 time stimulation of the dorsomedial prefrontal cortex affects
200 only spatial tasks while stimulation of the ventral portion af-
201 fects only non-spatial task (Mottaghy et al., 2002b). A recent
202 review of TMS studies of WM highlighted the involvement of
203 prefrontal cortex both in maintaining the transient patterns
204 of neural activity in other areas that maintain information
205 available online, and in executive processes (Mottaghy, 2005).

206 The aim of this experiment was to evaluate the relative
207 contributions of the left and right DLPFC to sentence compre-
208 hension, by comparing the effects of rTMS applied to these
209 two regions. The experiment involved the presentation of
210 a sentence and two pictures (see Fig. 1). Subjects were re-
211 quired to judge which of the two pictures correctly matched
212 the meaning of a semantically reversible sentence (subject-
213 verb-object) in the active or passive form. In the syntactic con-
214 dition, one picture matched the true meaning of the sentence,
215 while in the "distracter" picture the subject and the object of
216 the action were reversed. In the semantic condition, the dis-
217 tracter did not correspond to the meaning of the sentence be-
218 cause the subject, object or action did not correspond to the
219 presented lexical items. rTMS was delivered over left or right
220 DLPFC, at a frequency of 10 Hz for a period of 900 msec, start-
221 ing 100 msec after the onset of the display. The paradigm was
222 chosen with the idea to minimise the involvement of the re-
223 tention component of WM, since the information is always
224 present to the subject, and to require the manipulation of
225 the linguistic and pictorial information in order to allow the
226 correct resolution of the matching task. On the basis of lesion
227 and imaging data, we predicted a greater interference with
228 left-sided stimulation, in particular on the syntactic task.
This could be attributed to a distant effect in the ventrolateral
cortex, responsible for syntactic processing, or to a direct ef-
fect on the manipulation component of WM.

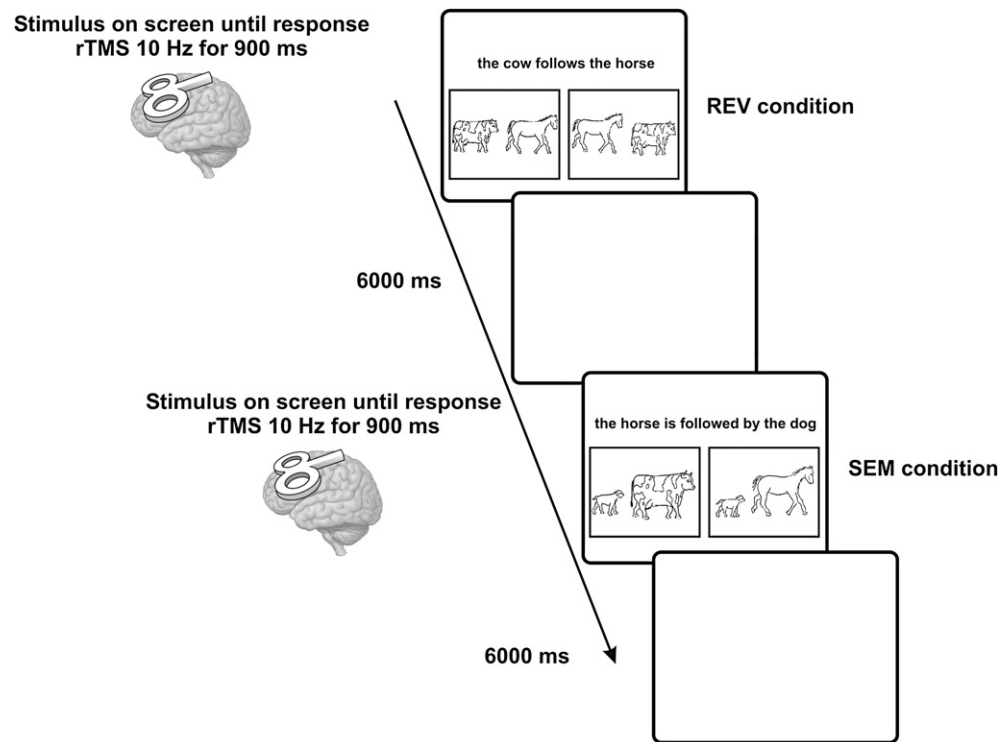


Fig. 1 – Presentation of stimuli and rTMS paradigm. rTMS was delivered 100 msec after the onset of the display, which was composed of a sentence and two pictures, and lasted 900 msec (10 stimuli). Participants were instructed to press a left or right key according to the location of the picture consistent with the sentence. The display stayed on the screen until the subject gave a response.

2. Methods

2.1. Subjects

A group of 12 subjects (mean age = 27.33 years; mean education = 17.67 years) participated in the experiment. All subjects were native Italian speakers and had normal or corrected-to-normal visual acuity. Participants reported being free of neurological disorders or history of seizures. All were right handed, with a mean score on the Edinburgh Handedness Inventory of +81.33. Participants were informed about the possible risk of rTMS and informed consent was obtained after a safety screening. The experimental methods had ethical approval from the local Human Ethics Committee.

2.2. Stimuli

The stimuli had been selected from the oral and written sentence comprehension task in the “Batteria per l’Analisi dei Deficit Afasici – B.A.D.A.” (Miceli et al., 1994). A sentence and two pictures made up each display. All sentences were made up of two noun phrases and one verbal phrase (i.e. “la mucca segue il cavallo” “the cow follows the horse”), with a mean length in letters of 26.71 (range 21–37) and a mean length in words of 5.56 (range 5–7). All the experimental sentences and their translations are reported in the [Appendix](#). The stimuli

were presented in black lower-case letters (Times New Roman font size 30) on a white background.

A total of 58 sentence–picture pairs were constructed: 48 for the three experimental blocks (16 for each one), and 10 for the practice session. The subjects’ task was to match the sentence with one of the two pictures. The “distracter” picture could be of two different types: (1) in the semantic condition, “SEM”, for the sentence “the horse is followed by the dog” (il cavallo è seguito dal cane) the wrong picture depicted a cow followed by a dog; (2) in the syntactic condition, in which the sentence was reversible, “REV”, for the sentence “the cow follows the horse” (“la mucca segue il cavallo”) a wrong picture could depict a horse following a cow. In the latter type of trials, morpho-syntactic information is crucial because the subject must correctly comprehend the structure of the sentence to solve the task correctly. Failure to respond correctly to “REV” trials would seemingly indicate a failure to process morpho-syntactic information. In the SEM condition, the crucial information could have been in one of the two noun phrases (e.g. a wrong picture could depict a cow followed by a dog or a horse followed by a cat), or in the verbal phrase (e.g. the wrong picture depicts a horse *frightened* by a dog). The two pictures used in a trial were always different along one of the two possible dimensions (SEM and REV), and in all the trials there was only one picture that correctly matched the sentence. Each block contained an equal number of SEM and REV trials, presented in a pseudo-random order, and in each condition sentence form (active or passive), position of

the relevant information (the first or the second noun phrase or the verb phrase for the semantic condition), and position of the correct picture (left or right), as well as stimulation site (left, midline sham or right rTMS), were counterbalanced.

2.3. Procedure

Subjects sat in a dimly lit room facing a computer monitor. The stimuli were presented using Presentation software (Version 0.70, www.neurobs.com) running on a personal computer with a 17-inch screen. At the beginning of each trial, one sentence and two pictures were presented. The sentence was located at the top of the screen above the two pictures, which were on the left and right side of the screen (see Fig. 1). The subjects were asked to judge which of the two pictures was an accurate representation of the sentence. Subjects made a speeded decision via a two-choice button press, using both hands. The visual stimulus stayed on the screen until a response was given and a blank screen lasting 6000 msec was interspersed between trials. The whole session, including preparation, lasted about 40 min.

2.4. rTMS procedure

rTMS was applied using a Magstim Rapid with a figure-of-eight (double 70 mm) coil which can induce a maximum magnetic field of 2.2 T at the scalp site. Before the experiment, individual resting motor excitability thresholds of stimulation were determined by stimulating the left motor cortex and inducing a contraction evoked by a single TMS pulse in the contralateral first interosseus dorsalis muscle. The threshold was defined as the minimum intensity that induced a visible contraction in the tested muscle, as agreed by two experimenters on at least three out of six trials. The stimulation intensity used during the experiment was set at 90% of each subject's threshold. The mean stimulation intensity was 56.7% (min. 48%, max. 65%) of the maximum of the stimulator output. During the experiment, rTMS was delivered using a train of 10 pulses with a frequency of 10 Hz (i.e. lasting a total of 900 msec), starting 100 msec after trial onset. On the basis of evoked response studies, this was chosen as an ideal time window for interference with sentence comprehension task (Hald et al., 2006; Eckstein and Friederici, 2005; Haarmann and Cameron, 2005; Haarmann et al., 2005). Moreover, we decided to use a 10 Hz frequency to reduce the amount of overall stimuli delivered to each subject. This line of reasoning was based on the aim to keep stimulation on a safe side as much as possible (Wassermann, 1998).

Although individual radiological head images (i.e. magnetic resonance images – MRIs) were not available for our subjects, we localized left and right DLPFCs using the SofTactic Evolution navigator system (Version 1.0, www.emsmedical.net). This system allows the reconstruction of cerebral cortex in Talairach coordinates, with an accuracy of ~1 cm, on the basis of digitized skull landmarks (nasion, inion and two preauricular points) from which 50 uniformly distributed points can be mapped out on the scalp (3D Fastrak Polhemus digitizer) and then can be related to cerebral anatomy. An estimation of the single subject's cerebral volume is obtained by "Point-based Warping" to a MRI template and a 3D virtual

reconstruction based on the points recorded from the subject's scalp.

This method represents a good and cost-effective solution when single subject MRI scans are not available. It should be noted however that, while we can compute with very high precision the location of the coil, this does not strictly imply that we know the precise cerebral areas that are directly influenced by the magnetic field. Therefore, we can only assume that we were stimulating the estimated cortical site underlying the coil.

Using this system, we localized in each subjects the posterior region of BA 46 (Talairach coordinates $X = \pm 49$, $Y = 36$, $Z = 25$, middle frontal gyrus) at about halfway between F3/4 and F7/8, respectively, in the 10/20 EEG system. The subjects wore a close-fitting skullcap on which these positions were reproduced. To stimulate DLPFC cortex, we placed the anterior end of the junction of the two coil wings above this location marked on the skullcap.

The experiment included three blocks corresponding to three stimulation sites: left and right, which were estimated to overlie the left and right DLPFCs, and sham. The stimulation site for the sham condition was on the midline in the same coronal plane at the same horizontal level as the frontal sites but the coil being perpendicular to the scalp, thus ensuring that no effective magnetic stimulation reached the brain during the sham condition. Several approaches could be used to try to ensure that changes in performance are attributable specifically to the effects of TMS upon the brain. We decided to use both sham stimulation, as a baseline condition, and the stimulation of two homologous areas to compare the effects of rTMS upon different sites. Moreover, in our study we have also taken the approach of observing behaviour across two distinct tasks following the stimulation of one site (e.g. Beckers and Zeki, 1995). This technique is often used to try to ensure that effects of TMS are specifically due to the modulation of selected brain areas too.

3. Results

In order to assess the effects of site of stimulation on the two conditions, we analyzed accuracy and reaction time (RT) by means of repeated measures ANOVAs. Since the interaction between condition, site of stimulation and sentence form (active or passive) was not significant [$F(2,22) = 2.368$; $p > .12$], the data from the passive and active conditions were combined. Thus, in these analyses, the two factors were *condition* (semantic, SEM and syntactic, REV) and *site of stimulation* (left DLPFC, right DLPFC and sham rTMS). Analysis of accuracy [mean = 87.15%; semantic = 87.16% (left = 84.4%, right = 86.5%, sham = 90.6%); syntactic = 86.80% (left = 86.5%, right = 89.6%, sham = 84.4%)] showed no differences between main factors or significant interactions.

The RT analysis was performed only on correct responses that were less than two standard deviations from the mean RT (the 3% of the responses was eliminated). No significant differences were present for the two main factors [*condition*: $F(1,11) = .233$, $p > .05$; *site of stimulation*: $F(2,22) = .053$, $p > .05$], but there was a significant interaction between them [$F(2,22) = 9.623$, $p = .001$], indicating a differential effects of

the site of stimulation in the two conditions. This analysis was followed by planned comparisons (*t*-tests). As can be seen from Fig. 2, these comparisons confirmed that in the SEM condition stimulation of the left DLPFC slowed RTs (2744 msec) more than sham (2509 msec) or right (2429 msec) stimulation [left vs. sham: $t(11) = 2.111$, $p = .05$; left vs. right: $t(11) = 2.956$, $p = .013$]; while in the REV condition stimulation of the right DLPFC slowed RTs (2691 msec) more than left (2519 msec) or sham (2517 msec) stimulation. In this second set of analyses, the comparison between right and sham stimulation was significant [$t(11) = 2.449$, $p = .032$] and the difference between left and right stimulation also approached significance [$t(11) = 1.847$, $p = .092$]. No other effect reached significance.

4. Discussion

Our study was designed to evaluate the involvement of the left and right DLPFC in understanding semantically reversible active and passive sentences. The main result is a double dissociation of interference effects: rTMS applied to the left DLPFC slowed the performance in the lexical-semantic task; in contrast, rTMS applied to the right DLPFC slowed the performance in the syntactic task.

These results were not predicted on the basis of the lesion and imaging evidence. A disorder of syntactic comprehension is usually associated to agrammatic Broca's aphasia, due to lesions involving the left ventrolateral prefrontal cortex. Lexical-semantic comprehension impairments are typically found in patients with left post-rolandic damage.

This apparent discrepancy may be an example of the fallacy of the "virtual lesion" interpretation of TMS effects. The mechanism of action of TMS is to induce electric currents that produce excitation or inhibition in restricted pools of superficial cortical neurons underneath the coil. In the last few years, the combined use of TMS and functional imaging techniques has allowed the investigation of TMS influence on the underlying cortical areas. In a combined rTMS-PET study, Mottaghy et al. (2000) demonstrated that rTMS to the right or

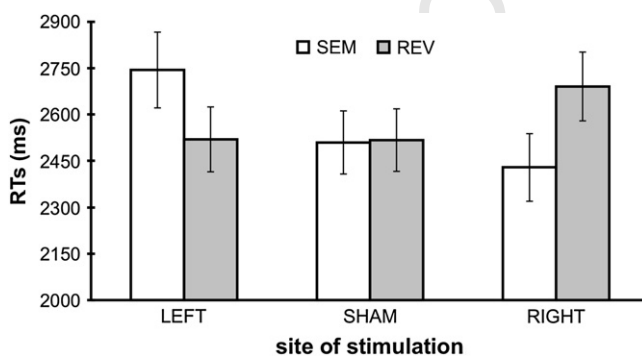


Fig. 2 – Behavioural results of the experiment. The graph shows reaction times for the three stimulation sites (left, sham and right rTMS), and the two conditions (semantic, SEM and syntactic, REV). As can be seen, rTMS to the left slowed RTs in the SEM condition while rTMS to the right slowed RTs in the REV condition. Vertical bars represent standard errors of the mean.

left DLPFC can worsen performance in a verbal WM task while inducing significant reductions in rCBF both at the stimulation site and at distant brain regions. These results underlined the ability of rTMS to produce temporary functional modulations of a neuronal network involved in the selected behavioural task that result in a modification of subjects' performance. Therefore, it is reasonable that the effects highlighted in rTMS studies cannot be totally and directly compared with lesion studies. Nevertheless, the effects of TMS in the cognitive neuroscience field have often been interpreted as the consequence of a transient lesion, which may avoid problems related to cortical plasticity, functional reorganization, individual differences on subject ability or lesion localization. However, the use of TMS as an interference tool has never produced a clear deficit in the subject performance, like in patients. The type of effect is often related on increased timing in the information processing (e.g. increased reaction time) and, if a reduction of subject performance is recorded, it is most likely explained by the complexity of the processing needed to solve the task; for that reason the effect of TMS may be related to the reduction of the difference between the signal and the noise present in the system. Therefore, TMS can be regarded as an interference method that can increase the timing for the information processing or modify criteria for response decision.

With these considerations in mind, we can attempt an interpretation of the hemisphere-specific interference effects.

In the semantic condition, the subject had to compare two noun phrases and one verb phrase with their possible pictorial representations. This task requires the retention and the manipulation of lexical-semantic information in WM. Hanten and Martin (2001), Martin and Romani (1994), Martin et al. (1994, 1999) have argued that the span tasks usually adopted to measure verbal WM tap both phonological and semantic retention. The phonological component of span tasks is independent of the capacity involved in sentence processing, as indicated by the neuropsychological observations of patients with difficulty retaining phonological information who nevertheless show preserved sentence comprehension. In contrast, the semantic component plays a crucial role in sentence comprehension in the maintenance of word meanings prior to their integration with other word meanings. Patients with a semantic retention deficit are impaired in detecting the presence of a semantic anomaly in sentences with multiple adjectives preceding a noun (e.g. "The wooden big black coat") or with several nouns preceding a verb (e.g. "Priests, melons and cherries can be usually bought in shops"). The same patients' performance improved when the adjectives followed the noun or the nouns followed the verb.

A specific role of left prefrontal cortex in the retention and manipulation of semantic information is supported by recent lesion findings. A study evaluating a large number of left hemisphere injured patients, found that lesions of middle and superior temporal gyrus, mid-frontal cortex in Brodmann's area 46 and Brodmann's area 47 of the inferior frontal gyrus affected comprehension performance evaluated with the Curtis-Yamada Comprehensive Language Evaluation (Curtiss and Yamada, 1988), while lesions of Broca's and Wernicke's areas did not significantly modify language comprehension evaluated with this test (Dronkers and Ogar, 2004).

In the syntactic condition of the experiment, the participants had to create a representation of the meaning of the entire sentence, which resulted in the identification of the thematic roles of the lexical items (agent and subject) on the basis of a syntactic analysis, and to compare it with the two presented pictures. This process was prone to interference by right-sided, rather than by left-sided rTMS to the MFG. As pointed out in Section 1, this is an area which is considered to play an important role in the manipulation of spatial information in WM (Leung et al., 2002; Rowe and Passingham, 2001; Van der Linden et al., 1999; Stern et al., 2000; Koch et al., 2005), and thus its role in sentence comprehension was unexpected. The idea of a possible involvement of spatial processes in language understanding can be traced back to Luria's interpretation of the syndrome of semantic aphasia (Luria and Hutton, 1977), characterized by the defective comprehension of logic-grammatical structures, as due to a disturbance of "simultaneous, spatial schemes". More recently, it has been proposed that the mapping of grammatical categories (subject, object) onto thematic roles (agent, patient) may be based on spatial representations, and thus be particularly sensitive to right hemispheric damage. Some clinical observations support this idea (Chatterjee et al., 1995a, 1995b; Warrington, 2000). The hypothesis that the logical structure of a sentence, independent of its syntactic structure, is represented in space

according to a left-to-right "language line" is supported by the recent observation that patients affected by hemi-inattention tend to neglect the position of the subject noun phrase in sentence presented auditorily. This is in the left part of the sentence in the case of actives, but on the right side for passive sentences (Rinaldi and Pizzamiglio, 2005).

It is noteworthy that in the case of imaging studies, an increase in "complexity" of a sentence, both in terms of syntactic structure and of WM requirements, has been associated with more extensive brain activation, extending to the right hemisphere (Just et al., 1996). The recruitment of right-sided areas has been associated with the processing of visuo-spatial content (Drummond et al., 2003; Carpenter et al., 1999).

In conclusion, we propose an interpretation of the observed double dissociation in terms of interference with specific WM resources, related to each hemisphere. In particular, in the case of the semantic condition, left TMS had an influence on subjects' performance since it interfered with verbal WM, while in the case of syntactic condition right TMS slowed participants' performances since it interfered with visuo-spatial memory during sentence-picture matching. In particular, since we minimized the involvement of the retention component, these effects may be attributed to an interference with the manipulation of semantic or syntactic information.

Appendix.

Experimental sentences

Active

Syntactic condition

i gatti inseguono i cani
(the cats chase the dogs)
la macchina segue il camion
(the car follows the lorry)
le mamme baciano i bambini
(the mothers kiss the children)
le moto hanno superato le macchine
(the motorcycles outpaced the cars)
il cavallo spaventa le bambine
(the horse frightens the girls)
le donne spingono gli uomini
(the women push the men)
le mamme accarezzano le bambine
(the mothers caress the girls)
i gatti inseguono i palloni
(the cats chase the balls)
le moto hanno superato la macchina
(the motorcycles outpaced the car)
il ladro insegue il poliziotto
(the robber chases the policeman)
la moto ha superato la macchina
(the motorcycle outpaced the car)
l'autobus segue la macchina
(the bus follows the car)

Syntactic condition

la moto insegue la macchina
(the motorcycle chases the car)
il bambino indica la donna
(the boy points to the woman)
l'uomo pettina la bambina

Passive

il cavallo è inseguito dal cane
(the horse is chased by the dog)
il nonno è seguito dal bambino
(the grandfather is followed by the child)
le bambine sono applaudite dal bambino
(the girls are applauded by the boy)
la cartella è coperta dai libri
(the bag is covered by the books)
le bambine sono precedute dai bambini
(the girls are preceded by the boys)
i topi sono spaventati dai nonni
(the mice are frightened by the grandfathers)
la macchina è inseguita dalla moto
(the car is chased by the motorcycle)
le donne sono inseguite dagli uomini
(the women are chased by the men)
i topi sono assaliti dai gatti
(the mice are assailed by the cats)
la mamma è pettinata dal bambino
(the mother is combed by the child)
i ladri sono inseguiti dai poliziotti
(the rubbers are chased by the policemen)
le ballerine sono applaudite dal bambino
(the dancers are applauded by the boy)

il nonno è indicato dal bambino
(the grandfather is pointed by the child)
le bambole sono pettinate dalle bambine
(the dolls are combed by the girls)
il nonno è accompagnato dal ragazzo

Experimental sentences (continued)

Active	Passive
(the man combs the girl)	(the grandfather is accompanied by the boy)
le bambine pettinano i bambini	la macchina è preceduta dall'autobus
(the girls comb the boys)	(the car is preceded by the bus)
i nonni accompagnano la bambina	l'autobus è tirato dal camion
(the grandfathers come with the girl)	(the bus is dragged by the lorry)
i cani inseguono i gatti	la moto è stata superata dalla macchina
(the dogs chase the cats)	(the motorcycle is exceeded by the car)
il medico saluta il bambino	i nonni sono spaventati dai gatti
(the physician says goodbye to the boy)	(the grandfathers are frightened by the cats)
il cavallo insegue il cane	gli uomini sono spinti dalle donne
(the horse chases the dog)	(the men are pushed by the women)
i bambini applaudono le ballerine	i conigli sono spaventati dai gatti
(the boys applaud the dancers)	(the rabbits are frightened by the cats)
la bambina abbraccia le ballerine	il ladro è inseguito dal poliziotto
(the girl hugs the dancers)	(the robber is chased by the policeman)
i pagliacci fischiano al cantante	il camion è spinto dall'autobus
(the clowns clap the singer)	(the lorry is pushed by the bus)
le donne inseguono gli uomini	il bambino è seguito dal nonno
(the women chase the men)	(the child is followed by the grandfather)

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