Left But Not Right Temporal Involvement in Opaque Idiom Comprehension: A Repetitive Transcranial Magnetic Stimulation Study

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Abstract

■ It has been suggested that figurative language, which includes idioms, is controlled by the right hemisphere. We tested the right hemisphere hypothesis by using repetitive transcranial magnetic stimulation (rTMS) to transiently disrupt the function of the frontal and temporal areas of the right versus left hemisphere in a group of normal participants involved in a task of opaque idiom versus literal sentence comprehension. Forty opaque, nonambiguous idioms were selected. Fifteen young healthy participants underwent rTMS in two sessions. The experiment was run in five blocks, corresponding to the four stimulated scalp positions (left frontal and temporal and right frontal and temporal) and a baseline. Each block consisted of 16 trials—8 trials with idioms and 8 trials with literal sentences. In each trial, the subject was presented with a written sentence, which appeared on the screen for 2000 msec, followed by a pair of pictures for 2500 msec, one of which corresponded to the sentence. The alternative corresponded to the literal meaning for idioms and to a sentence differing in a detail in the case of literal sentences. The subject had to press a button corresponding to the picture matching the string. Reaction times increased following left temporal rTMS, whereas they were unaffected by right hemisphere rTMS, with no difference between idiomatic and literal sentences. Left temporal rTMS also reduced accuracy without differences between the two types of sentences. These data suggest that opaque idiom and literal sentence comprehension depends on the left temporal cortex. ■

INTRODUCTION

In our speech, we make use of expressions that are not necessarily interpreted on a literal ground: Idioms are among the most common forms of figurative language (Gibbs, 1999). Although differing in many respects, these expressions share a semantic eccentricity: Their meaning is not a direct function of the meanings of their component words.

There are two main theories to explain idiom comprehension. The ‘‘lexical representation hypothesis’’ (Swinney & Cutler, 1979) suggests that idioms are mentally represented and processed as lexical items, that is, particularly long words. Alternatively, the ‘‘configurational hypothesis’’ (Tabossi & Zardon, 1995; Cacciari & Tabossi, 1988) proposes that idiomatic expressions may be mentally represented and processed as configurations of words and their meaning becomes activated after a word in a key position has been found.

Idioms may exhibit a certain degree of lexical flexibility and productivity (Gibbs, Nayak, & Cutting, 1989) and undergo syntactic processing even after their figurative meaning has been retrieved (Peterson, Burgess, Dell, & Eberhard, 2001). They range from expressions that are almost like long words (e.g., ‘‘by and large’’) to expressions that are like metaphors (e.g., ‘‘take the bull by the horns’’) (Glucksberg, 2001). In between, there is the majority of idioms, in particular verbal idioms, which are syntactically and semantically processed, and accordingly can undergo syntactic and semantic variations.

Idioms can vary along a number of dimensions. The main characteristic of idioms is conventionality, which means that the meaning of an idiom cannot be predicted based on knowledge of the rules that determine the meaning or use of its parts when they occur in isolation from one another.

A second feature is their opacity/transparency, which means the ease with which the motivation for their use can be recovered. Idioms can involve figuration and can be originally metaphorical (‘‘take the bull by the horns’’), even if speakers may not always perceive the precise motive for the figure involved (Nunberg, Sag, & Wasow, 1994), but there are some idioms that do not involve figuration. In transparent expressions, speakers can wholly recover the rationale for the figuration involved, although this is not the case for opaque idioms.

Another dimension of idioms is compositionality, which refers to the fact that although idioms have conventional meanings, at least some of them are

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combining expressions, and idiomatic interpretation can be distributed over their parts. In contrast, non-decomposable idioms must be entered in the lexicon as complete phrases.

Finally, idioms can differ in the extent to which they can be syntactically transformed and still retain their idiomatic meaning (Gibbs & Gonzales, 1985): This depends on the degree of their syntactic frozenness.

In summary, idioms are not a unitary class of expressions. These properties make hard to believe that exactly the same processes are involved in the interpretation of all kinds of idioms and suggest that it is more sensible to study them separately, according to their features.

All these lexical and syntactic properties suggest that left hemisphere injuries, resulting in aphasic impairments, ought to damage, along with other linguistic abilities, patients' ability to comprehend idioms. However, a widely accepted view in neuropsychology assumes that a left brain damage has no major consequences, and it is the right hemisphere that is important for the processing of idiomatic expressions (see Burgess & Chiarello, 1996; Kempler & Van Lancker, 1993; Van Lancker & Kempler, 1987; Foldi, Cicone, & Gardner, 1983), although psycholinguistic models all stress the importance of lexical knowledge (Tabossi & Zardon, 1995; Swinney & Cutler, 1979), and increasing evidence indicates the involvement of syntactic processing (Peterson et al., 2001) in the comprehension of idioms.

There are, however, many limits in neuropsychological studies on idioms. First of all, items are not chosen considering their intrinsic, linguistic features, and are examined together with proverbs and courtesy phrases as ''familiar language'' (Kempler, Van Lancker, & Bates, 1999; Van Lancker & Kempler, 1987). The severity of aphasia and the modalities of assessment are not always described in detail; time of testing with respect to the time of onset of aphasia is variable and it is not clear whether patients underwent language rehabilitation; other neuropsychological deficits are not reported; the number of stimuli is limited. Moreover, in one of these studies (Van Lancker & Kempler, 1987), the performance of aphasic patients cannot be considered normal since the score is around 72% correct for idioms, compared with a controls' performance of 97.3%. The same aphasic subjects scored 90% correct on word comprehension.

Although some authors (Tompkins, Boada, & McGarry, 1992) challenge the involvement of the right hemisphere in idiom comprehension without assigning a particular role to the left hemisphere, other studies have shown that the left hemisphere, and not the right, has a role in idiom comprehension (Papagno & Tabossi, 2002). In the study by Tompkins et al. (1992), an on-line mo-nitoring task was used to assess right-brain-damaged, left-brain-damaged, and normally aging adults' implicit knowledge of familiar idiomatic expressions. Brain-damaged subjects performed similarly to normal controls on this task, although the pathological group fared poorly by comparison on an off-line idiom-definition measure. The authors concluded that adults with unilateral brain damage can activate and retrieve familiar idiomatic forms, and that their idiom interpretation deficits most likely reflect an impairment at some later stage of information processing. Therefore, they stressed the role of idiom interpretation tasks in determining results.

To further test the contribution of specific regions of the right and the left hemisphere in idiomatic language processing (Kempler et al., 1999), in the present study, we decided to use an interference approach by means of repetitive transcranial magnetic stimulation (rTMS). TMS can be used to disrupt, reversibly and transiently, the normal activity of a brain area (Siebner & Rothwell, 2003; Pascual-Leone, Walsh, & Rothwell, 2000). Because it is an interference technique, an advantage of TMS is that it can be used to demonstrate not only that a brain region is active while a given task is performed, but also that the area is actually essential for task performance. In addition, it allows studying healthy subjects, eliminating the confounding effects of the diffuse impairment and compensatory cortical plasticity associated with brain lesions, and thus complementing neuropsychological studies. We used trains of pulses at 1 Hz frequency, which are known to reduce the excitability of the targeted region, and so to interfere with cognitive processing beyond the duration of the train itself (Koch, Oliveri, Torriero, & Caltagirone, 2003; Hilgetag, Theoret, & Pascual-Leone, 2001; Shapiro, Pascual-Leone, Mottaghy, Gangitano, & Caramazza, 2001; Maeda, Keenan, Tormos, Topka, & Pascual-Leone, 2000; Pascual-Leone et al., 2000; Chen et al., 1997).

Given the fact that idioms are not homogeneous, we chose a particular class of idioms, opaque idioms. The meaning of these expressions must once have been learned and their comprehension requires, among other things, their identification and retrieval from memory (Papagno, 2001). Different processes could be involved in interpreting transparent idioms.

RESULTS

All participants tolerated rTMS well and did not report any adverse effects. The average motor threshold was $50 \pm 5\%$ for the left hemisphere and $52 \pm 4.6\%$ of the maximum stimulator output for the right hemisphere ($p > .05$, Student's t test). Therefore, in each subject, the average intensity of rTMS was the same for both cerebral hemispheres.

rTMS significantly modulated subjects' performance compared with baseline trials. In particular, as shown in Figure 1A, reaction times (RTs) increased following left hemisphere rTMS, while were unaffected by right hemisphere rTMS, $F(4,56) = 2.9$, $p = .03$. The sentence main

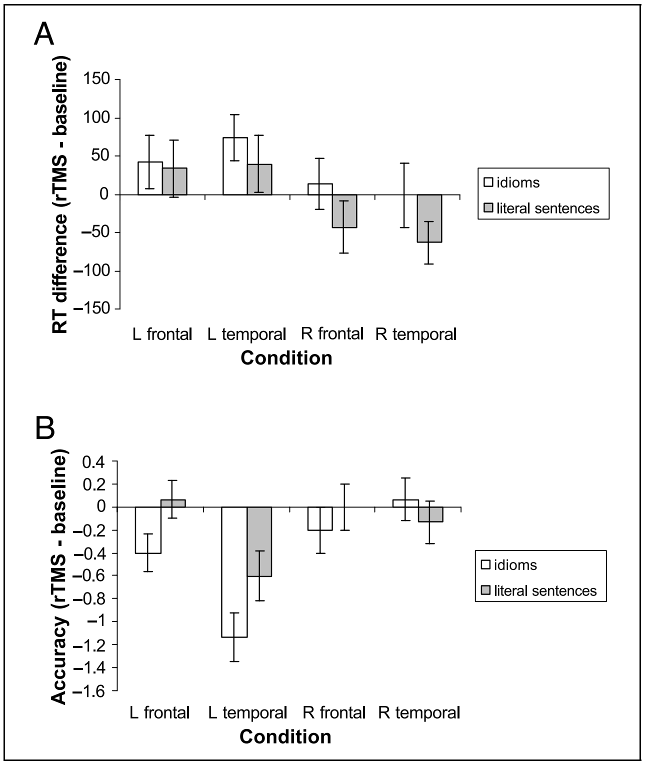

Figure 1. (A) Average delta RTs (rTMS − baseline difference) as a function of the stimulated scalp positions. (B) Average delta accuracy (rTMS − baseline difference) as a function of the stimulated scalp positions. L = left; R = right. Error bars indicate 1 *SEM*.

effect was not significant, $F(1,14) = 2.7$, $p = .1$. The effect of rTMS did not differ between idiomatic and literal sentences, $F(4,56) = 0.7$, $p = .6$. Planned comparisons showed that left temporal rTMS significantly increased mean RTs as compared with baseline ($p < .05$), right frontal ($p < .05$), and right temporal ($p < .005$). Left frontal rTMS significantly increased mean RTs as compared with right temporal rTMS ($p < .02$), whereas the difference between left frontal and right frontal rTMS only approached significance ($p = .07$) (see Figure 1A).

Regarding accuracy, we found a significant main effect of sentence, $F(1,14)=14.9$, $p < .005$, indicating an overall better accuracy with idiomatic as compared with literal sentences. rTMS significantly reduced accuracy, $F(4,56) = 4.7$, $p < .01$, without significant differences between idioms and literal sentences, $F(4,56) = 1.04$, $p = .4$ (see Figure 1B).

Planned comparisons showed that left temporal rTMS significantly reduced the number of correct responses as compared with baseline ($p < .0005$), left frontal ($p < .005$), right frontal ($p < .005$), and right temporal rTMS ($p < .001$). In the control experiment performed to confirm the specific disruption of left hemispheric rTMS with the linguistic task, we found an opposite hemispheric effect in a task requiring to make spatial judgments on the same stimuli: In this case, rTMS of the right frontal site significantly increased RTs compared with baseline trials and trials with left frontal rTMS, $F(3,5) = 20$; $p < .005$. The effect was independent from the kind of stimuli [idioms vs. literal sentences, $F(3,5) = 0.4$, $p > .05$]. The mean accuracy in this task was not affected by rTMS.

DISCUSSION

Previous neuropsychological studies have provided equivocal results in identifying which brain regions appear essential for idiomatic sentence comprehension. In the present experiment, we used rTMS to test for the presence of hemispheric differences in idiomatic language processing, focusing our analysis on the posterior temporal and frontal cortices. We chose to analyze a particular class of idioms, opaque idioms, because one cannot exclude that other types, such as transparent idioms, are submitted to different processing and do not share the same anatomical correlates, as it has been found to be the case for different grammatical classes, such as verbs and nouns (Shapiro et al., 2001). The main results of our experiment show that only left temporal rTMS significantly disrupted performance, increasing RTs and reducing accuracy both for literal sentences and idiomatic phrases. Left frontal rTMS induced a less prominent disruption, whereas right temporal rTMS facilitated subjects' performance, reducing RTs and improving accuracy for both idioms and literal sentences. This opposite pattern of facilitation with right hemisphere rTMS may further support the claim regarding a left, and not right, hemisphere role for opaque idiom comprehension. In fact, previous studies have shown that TMS of one region may disinhibit the homologous regions in the contralateral hemisphere (Hilgetag et al., 2001; Oliveri et al., 1999, 2000, 2001; Seyal, Ro, & Rafal, 1995). If such a disinhibition mechanism was operating in this study, the faster RTs after right hemisphere rTMS may have been due to disinhibition of the left hemisphere, producing better performance on literal and idiom comprehension in this condition.

Unspecific factors related to TMS procedure cannot account for this selective hemispheric effect, since the motor threshold, and so the intensity of TMS, was the same for all stimulated scalp sites. Moreover, in the control experiment in which the subjects were required to make a spatial judgment about the alignment of the same stimuli, rTMS of the right, but not the left, frontal cortex disrupted performance, thus ruling out the possibility that left hemisphere rTMS may just be generally disruptive for any task rather than being specific for opaque idiom and literal sentence comprehension. Therefore, the present results suggest an essential role for the left hemisphere in idiomatic sentence comprehension.

These findings can be interpreted on the light of a recent neuropsychological study (Papagno & Genoni, in press), suggesting that syntactic processing, strictly dependent on the activity of the left hemisphere, can be a crucial factor for idiom interpretation. The performance of a group of aphasic patients correlated (a) with the performance in the literal sentence comprehension, (b) with syntactic competence, and in particular, (c) with the patients' ability to recognize whether idioms were presented in their syntactically correct form. In the present study, there was also some equivocal evidence for an effect of left frontal rTMS on idiomatic processing. The asymmetry of the inhibition by the dorsolateral prefrontal cortex is not new, considering that event-related potential studies have already shown such effect, for example, in case of visual irrelevant information (Zani & Proverbio, 2002) and in case of dichotic attention tasks (Woods & Knight, 1986). In fact, stimulation of the left frontal region disrupted performance compared with right temporal rTMS, while it failed to sig-nificantly affect it when compared with right frontal rTMS and with baseline trials. Indeed, this result appears surprising, considering that idiomatic language can be impaired not only because of lexical–semantic and syntactic deficits as observed in aphasic patients (Papagno & Tabossi, 2002), but also by different mechanisms directly involving frontal cortex, such as impaired executive functions (Papagno, 2001; Papagno & Vallar, 2001; Papagno, Lucchelli, Muggia, & Rizzo, 2003). Gernsbacher and Robertson (1999) had already described the crucial role that suppression plays in many aspects of language comprehension. They defined suppression as a general, cognitive mechanism, the purpose of which is to attenuate the interference caused by the activation of extraneous, unnecessary, or inappropriate information. Sometimes, this superfluous activation arises from the external environment, as when we conduct a conversation in a noisy place. Other times, this superfluous information is activated internally, as when we have to deal with the competing meanings of a word or phrase. In case of idiomatic expressions, the literal and the figurative interpretation can be activated in parallel, so that a mechanism for attenuating the activation of the inappropriate interpretation is needed. The presence of two alternatives, in particular for idioms, could induce a Stroop effect. Brega and Healy (1999) showed that sentence processing could be obligatory when the component words are highly relevant to the task. The central executive would be responsible of the inhibition of the literal meaning, so that we would have expected a frontal effect of rTMS. A possible explanation is the following. Giora and Fein (1999) suggested that hearing familiar idioms should lead to both their idiomatic and literal interpretations becoming activated, because both interpretations are salient outside of context. According to their view, the literal interpretation of an idiom is functional for idiom interpretation. Therefore, they predict that with familiar idioms, deriving the literal interpretation does indeed involve suppressing the idiomatic interpretation; however, they propose that deriving the idiomatic interpretation requires retaining the literal interpretation. In the case of an absolutely implausible expression or containing a syntactic violation (Papagno & Tabossi, 2002), the literal meaning is less salient and can be easily rejected. This would reduce the role of selection and response inhibition and, therefore, the activation of the frontal executive processes could not be critical in the task. The low level of activation of frontal cortex could explain why a localized modulation of its excitability by means of rTMS does not interfere with the task of opaque idiom comprehension. On the other hand, the disrupting effect of brain damage with idiom comprehension described in aphasic patients could be explained by the more diffuse impairment, associated with plastic changes, created by the lesion. Further studies, using more alternatives in the task, could contribute to disentangle this question. In fact, the presence of more alternatives, is likely to emphasize the process of selection and so the level of activation of the frontal cortex, making it more sensitive to the effects of rTMS interference.

In conclusion, our results show that comprehension of a particular class of idioms, opaque idioms, as that of literal sentences, is strictly related to the activity of temporal areas of the left hemisphere. These results complement those of recent neuropsychological studies in aphasic patients, suggesting that syntactic processing could be a crucial factor in the interpretation of figurative language. We agree with the hypothesis suggested by Tompkins et al. (1992) that sensory or cognitive (such as visuospatial or visuoperceptual) deficits, which are frequently associated with right brain damage, can result in suboptimal processing of critical task elements or deplete available resources for further analysis; in this situation, subjects might be particularly likely to resort to the less demanding choice, which is the literal choice. Moreover, we would like to stress the fact that the left superior temporal cortex appears to be necessary in the process of idiom comprehension. This finding does not exclude that other brain sites in the right hemisphere could play a role.

We also underline that it is important to consider separately different aspects of figurative language, and in the future it will be interesting to assess rTMS disruption on the processing of transparent idioms.

METHODS

Material

Forty verbal unambiguous idioms were selected (see Appendix). They were rated as highly familiar by a group of 45 healthy Italian volunteers (31 women and 14 men, age 22–65). They were unambiguous, as either they were ill formed or their literal interpretation was unlikely (or both). They were also opaque: Their meaning could not be derived from the figuration they involved. Twenty idioms were short (with only a content word after the verb) and 20 were long (with two content words after the verb). For each of them, two line-drawing pictures were created: one representing the idiomatic interpretation and the other representing as well as possible the literal interpretation.

Forty sentences were selected from the Sentence Comprehension Task (Parisi & Pizzamiglio, 1970). They were matched in length to the idioms. For each sentence, two pictures were presented, one is correctly described by the sentence; the other corresponds to a sentence, which is identical except for a detail (i.e., the boy is pushing the girl vs. the boy is pushed by the girl) (see Figure 2).

Procedures

Fifteen healthy young Italian right-handed subjects (mean age 24 ± 2 years) participated in the experiment after providing written informed consent. The study was approved by the local ethical committee. rTMS was applied using a Cadwell high-frequency magnetic stimulator and a focal 8-shaped coil (outer diameter 70 mm). During the experiment, subjects sat comfortably on a chair. For each subject, first, it was identified the optimal scalp location for induction of motor-evoked potentials in the contralateral abductor pollicis brevis muscle. Single-pulse TMS was then applied at decreasing intensities over this site to determine motor threshold, following guidelines established by the International Federation of Clinical Neurophysiology (Rossini et al., 1994). The scalp positions for stimulation in each subject were determined according to the EEG 10–20 system coordinates and were a postero-superior temporal site corresponding to T5–T6 position and a frontal site corresponding to a position between F5(6) and F7(8), both on the left and right hemisphere. Anatomical localization of these positions on MRI scans performed in previous studies (Shapiro et al., 2001; Topper, Mottaghy, Brugmann, Noth, & Huber, 1998) has shown a correspondence of the temporal site to Brodmann's area (BA) 22 and of the frontal site to BA 44/45. Moreover, for the purposes of the present study, the presence of hemispheric asymmetries, rather than a precise intrahemispheric anatomical localization was the critical variable. The target positions were marked on tightly fitting Lycra caps worn by the subjects. rTMS was applied at 90% of motor threshold intensity and 1 Hz frequency in trains of 300-sec duration (i.e.,

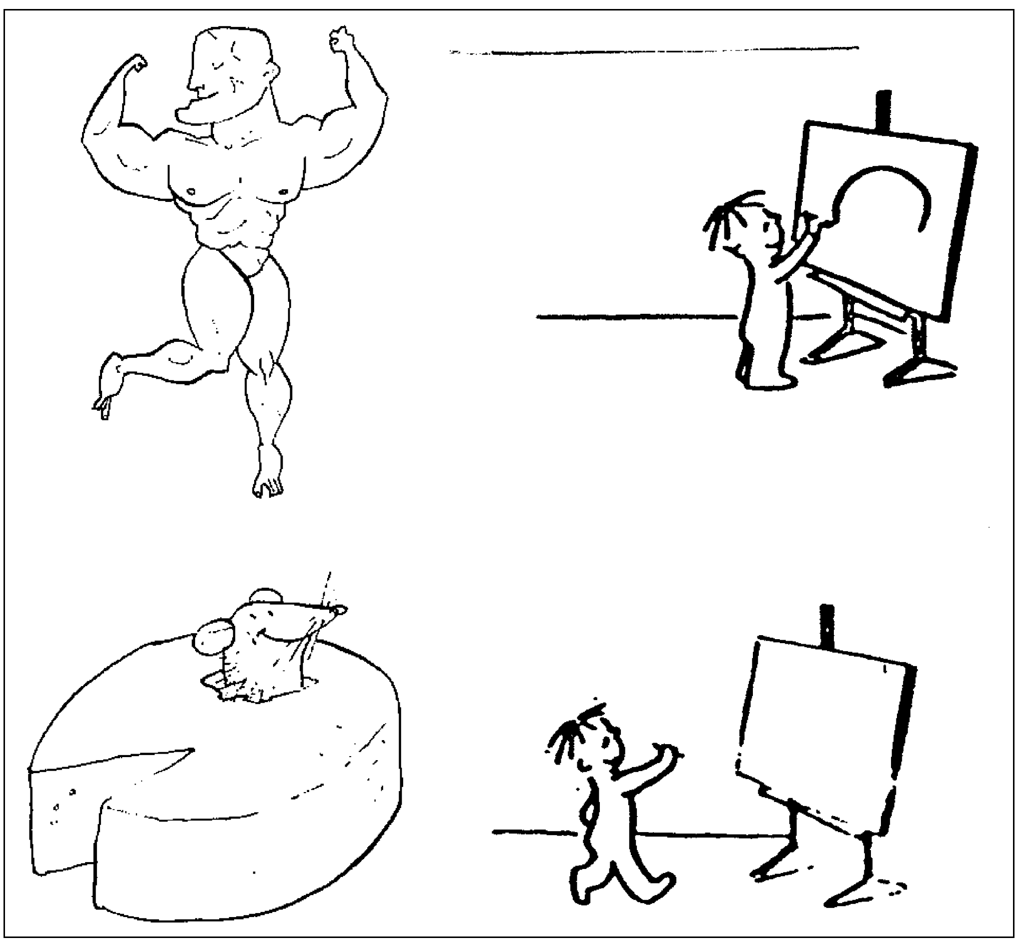

Figure 2. Examples of stimuli (idiom: "he is in shape"; literal sentence: "the child draws").

300 pulses) for each scalp site. The stimulation coil was applied tangentially on the subjects' scalp with the handle pointing posteriorly parallel to the subjects' midsagittal plane. rTMS of the two hemispheres was performed in separate days. Within each session, a 30-min rest period followed each block (temporal or frontal rTMS) to allow the effects of rTMS to wash out. The order of the stimulated hemispheres and scalp positions was randomized across subjects.

Experimental Task

A sentence-to-picture matching task was performed on a PC using SuperLab Pro. The experiment was run in five blocks, corresponding to the four stimulated scalp positions (left temporal, left frontal, right temporal, right frontal) and a baseline without rTMS. Each block—except the baseline—was presented immediately after the cessation of the rTMS train. It consisted of 16 trials—8 with idioms and 8 with literal sentences. The subject was presented with a written string, either an idiomatic expression or a literal sentence, which appeared on the screen for 2000 msec, followed by a pair of pictures for 2500 msec, one of which corresponding to the string. Participants had to press one of two buttons on the keyboard (left/right) corresponding to the figure matching the sentence.

In case of idioms, the subject had to choose between the picture corresponding to the figurative meaning and the one corresponding to the literal interpretation. In case of literal sentences, the subject had to choose between the picture corresponding to the sentence and a picture corresponding to an identical sentence except for a detail. Idioms were randomly intermingled with literal sentences. Response latencies and errors were recorded by the computer program. The position of the distractor picture was counterbalanced across trials. The stimuli pairs for each block were chosen based on a pilot experiment performed with 10 participants (different from those recruited for the main study) to balance the mean response time across the blocks. The order of stimuli within each block and the order of blocks were randomized and counterbalanced across participants.

A control experiment was run in four subjects, different from those included in the main study. In this experiment, we used the same stimuli employed in the first study and asked subjects to make spatial judgments about their alignment on the horizontal plane, ignoring the linguistic component of the task. The aim of this experiment was to verify that left hemispheric rTMS does not have a generalized disrupting effect for any task, but rather is specific for idiomatic sentence comprehension. The experiment was run in three blocks, corresponding to the two stimulated scalp positions (left frontal, right frontal) and a baseline without rTMS. The sequence of the events and the stimuli used were the same as in the main experiment (16 trials—8 with idioms and 8 with literal sentences, for each block). The only difference was that the borders of the pictures' pairs were not equidistant from the center of the screen, but positioned such that either the left or the right picture was shifted 5 mm from the center of the screen compared with the other one. After the presentation of the pictures' pairs, participants had to indicate which picture was more shifted from the center by pressing one of two buttons on the keyboard (left/right). In each block, stimuli were balanced to have the same number of left and right responses. The order of block presentation was randomized across subjects. This was possible because the mean accuracy and RTs were comparable for the three blocks of stimuli, as checked with a pilot experiment in 10 subjects.

Statistical Methods

RTs were excluded from the data if the subject responded incorrectly or if they fell outside the arbitrary range of 400–1500 msec. An ANOVA for repeated measures was performed on mean RTs and number of correct responses, with sentence (two levels: idiomatic vs. literal) and condition (five levels: baseline, left temporal, right temporal, left frontal, right frontal rTMS) as within-subject factors. Planned comparisons (LSD tests) were made. In the control experiment, an ANOVA with condition (three levels: baseline, right frontal, left frontal rTMS) and sentence (two levels: idiomatic vs. literal) as within subject factors was performed on mean RTs and number of correct responses. In both experiments, the level of significance was set at .05.

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REFERENCES

Brega, A. G., & Healy, A. F. (1999). Sentence interference in the Stroop task. *Memory and Cognition, 27,* 768–778.

Burgess, C., & Chiarello, C. (1996). Neurocognitive mechanisms underlying metaphor comprehension and other figurative language. *Metaphor Symbolic Activity, 11,* 67–84.

Cacciari, C., & Tabossi, P. (1988). The comprehension of idioms. *Journal of Memory and Language, 27,* 668–683.

Chen, R., Classen, J., Gerloff, C., Celnik, P., Wassermann, E. M., Hallett, M., & Cohen, L. G. (1997). Depression of motor cortex excitability by low-frequency transcranial magnetic stimulation. *Neurology, 48,* 1398–1403.

Foldi, N. S., Cicone, M., & Gardner, H. (1983). Pragmatic aspects of communication in brain damaged patients.

In S. J. Segalowitz (Ed.), *Language functions and brain organization* (pp. 51–86). New York: Academic Press.

Gernsbacher, M. A., & Robertson, R. R. W. (1999). The role of suppression in figurative language comprehension. *Journal of Pragmatics, 31,* 1619–1630.

Gibbs, R. (1999). Figurative language. In R. Wilson & F. Keil (Eds.), *The MIT encyclopedia of the cognitive sciences* (pp. 314–315). Cambridge: MIT Press.

Gibbs, R. W., & Gonzales, G. P. (1985). Syntactic frozenness in processing and remembering idioms. *Cognition, 20,* 243–259.

Gibbs, R. W., Nayak, N. P., & Cutting, C. (1989). How to kick the bucket and not decompose: Analyzability and idiom processing. *Journal of Memory and Language, 28,* 576–593.

Giora, R., & Fein, O. (1999). On understanding familiar and less-familiar figurative language. *Journal of Pragmatics, 31,* 1601–1618.

Glucksberg, S. (2001). *Understanding figurative language.* Oxford: Oxford University Press.

Hilgetag, C. C., Theoret, H., & Pascual-Leone, A. (2001). Enhanced visual spatial attention ipsilateral to rTMS-induced ''virtual lesions'' of human parietal cortex. *Nature Neuroscience, 4,* 953–957.

Kempler, D., & Van Lancker, D. (1993). Acquisition and loss of familiar language: Idiom and proverb comprehension. In F. R. Eckman (Ed.), *Language acquisition and language disorders* (vol. 4, pp. 249–257). Amsterdam: John Benjamins Publishing.

Kempler, D., Van Lancker, D., V., M., & Bates, E. (1999). Idiom comprehension in children and adults with unilateral brain damage. *Developmental Neuropsychology, 15,* 327–349.

Koch, G., Oliveri, M., Torriero, S., & Caltagirone, C. (2003). Underestimation of time perception after repetitive transcranial magnetic stimulation. *Neurology, 60,* 1844–1846.

Maeda, F., Keenan, J. P., Tormos, J. M., Topka, H., & Pascual-Leone, A. (2000). Modulation of corticospinal excitability by repetitive transcranial magnetic stimulation. *Clinical Neurophysiology, 111,* 800–805.

Nunberg, G., Sag, I. A., & Wasow, T. (1994). Idioms. *Language, 70,* 491–538.

Oliveri, M., Bisiach, E., Brighina, F., Piazza, A., La Bua, V., Buffa, D., & Fierro, B. (2001). rTMS of the unaffected hemisphere transiently reduces contralesional visuospatial hemineglect. *Neurology, 57,* 1338–1340.

Oliveri, M., Rossini, P. M., Filippi, M. M., Traversa, R., Cicinelli, P., Palmieri, M. G., Pasqualetti, P., & Caltagirone, C. (2000). Time-dependent activation of parieto-frontal networks for directing attention to tactile space. *Brain, 123,* 1939–1947.

Oliveri, M., Rossini, P. M., Traversa, R., Cicinelli, P., Palmieri, M. G., Pasqualetti, P., Tomaiuolo, F., & Caltagirone, C. (1999). Left frontal transcranial magnetic stimulation reduces contralesional extinction in patients with unilateral right brain damage. *Brain, 122,* 1731–1739.

Papagno, C. (2001). Comprehension of metaphors and idioms in patients with Alzheimer's disease. A longitudinal study. *Brain, 124,* 1450–1460.

Papagno, C., & Genoni, A. (in press). The role of syntactic competence in idiom comprehension: A study on aphasic patients. *Journal of Neurolinguistics.*

Papagno, C., Lucchelli, F., Muggia, S., Rizzo, S. (2003). Idiom comprehension in Alzheimer disease: The role of the central executive. *Brain,* 126.

Papagno, C., & Tabossi, P. (2002). Idiom comprehension in aphasic patients. *Brain and Language, 83,* 78–81.

Papagno, C., & Vallar, G. (2001). Understanding metaphors and idioms: A single-case neuropsychological study in a person with Down syndrome. *Journal of the International Neuropsychological Society, 7,* 516–528.

Parisi, D., & Pizzamiglio, L. (1970). Syntactic comprehension in aphasia. *Cortex, 6,* 204–215.

Pascual-Leone, A., Walsh, V., & Rothwell, J. (2000). Transcranial magnetic stimulation in cognitive neuroscience: Virtual lesion, chronometry and functional connectivity. *Current Opinion in Neurobiology, 10,* 232–237.

Peterson, R. R., Burgess, C., Dell, G. S., & Eberhard, K. (2001). Dissociation between syntactic and semantic processing during idiom comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 1223–1237.

Rossini, P., Barker, A., Berardelli, A., Caramia, M., Caruso, G., & Cracco, R. (1994). Non-invasive electrical and magnetic stimulation of the brain, spinal cord and roots: Basic principles and procedures for routine clinical application. Report of an IFCN committee. *Electroencephalography and Clinical Neurophysiology, 91,* 79–92.

Seyal, M., Ro, T., Rafal, R. (1995). Increased sensitivity to ipsilateral cutaneous stimuli following transcranial magnetic stimulation of the parietal lobe. *Annals of Neurology, 38,* 264–267.

Shapiro, K., Pascual-Leone, A., Mottaghy, F., Gangitano, M., & Caramazza, A. (2001). Grammatical distinctions in the left frontal cortex. *Journal of Cognitive Neuroscience, 13,* 713–720.

Siebner, H. R., & Rothwell, J. C. (2003). Transcranial magnetic stimulation: New insights into representational cortical plasticity. *Experimental Brain Research, 148,* 1–16.

Swinney, D. A., & Cutler, A. (1979). The access and processing of idiomatic expression. *Journal of Verbal Learning Verbal Behaviour, 18,* 523–534.

Tabossi, P., & Zardon, F. (1995). The activation of idiomatic meaning. In M. Everaert, E. J. van der Linden, A. Schenk, & R. Schreuder (Eds.), *Idioms: Structural and psychological perspectives* (pp. 273–282). Hillsdale, NJ: Erlbaum.

Tompkins, C. A., Boada, R., & McGarry, K. (1992). The access and processing of familiar idioms by brain-damaged and normally aging adults. *Journal of Speech and Hearing Research, 35,* 626–637.

Topper, R., Mottaghy, F. M., Brugmann, M., Noth, J., & Huber, W. (1998). Facilitation of picture naming by focal transcranial magnetic stimulation of Wernicke's area. *Experimental Brain Research, 121,* 371–378.

Van Lancker, D., & Kempler, D. (1987). Comprehension of familiar phrases by left but not by right hemisphere damaged patients. *Brain and Language, 32,* 265–277.

Woods, D. L., & Knight, R. T. (1986). Electrophysiologic evidence of increased distractibility after dorsolateral prefrontal lesions. *Neurology, 36,* 212–216

Zani, A., & Proverbio, M. (2002). *ERP indicants of a left-sided hemispheric asymmetry in prefrontal suppression of visual irrelevant information* (Program No 180.11). Washington, DC: Society for Neuroscience.

APPENDIX

	IF (0–3)	
1. “avere il pollice verde”	2.4	“to have the thumb green”
2. “andare al fresco”	2.3	“to go in the cool”
3. “avere la puzza sotto il naso”	2.5	“to have a bad smell under the nose”
4. “dare del filo da torcere”	2.6	“to give some thread to twist”
5. “essere in forma”	2.7	“to be in shape”
6. “andare in bestia”	2.5	“to go in beast”
7. “fare fiasco”	2.3	“to make flask”
8. “essere al settimo cielo”	2.5	“to be at the seventh sky”
9. “mandare a monte”	2.3	“to send to mountain”
10. “essere di facili costumi”	2.3	“to be of easy customs”
11. “prendere fischi per fiaschi”	2.3	“to take whistles for flasks”
12. “montarsi la testa”	2.7	“to mount the head”
13. “dare i numeri”	2.6	“to give the numbers”
14. “farsene un baffo”	2.4	“to make of it a moustache”
15. “avere i minuti contati”	2.5	“to have the minutes counted”
16. “stare alle costole”	2.3	“to stay at the ribs”
17. “avere il cuore in mano”	2.1	“to have the heart in hand”
18. “vendere cara la pelle”	1.9	“to sell at a high price the skin”
19. “venire alle mani”	2.4	“to come to the hands”
20. “mordere il freno”	1.4	“to bit the brake”
21. “parlare al muro”	2.7	“to talk to the wall”
22. “essere sul viale del tramonto”	1.9	“to be on the sunset boulevard”
23. “spremersi le meningi”	2.4	“to squeeze one’s meninges”
24. “essere di manica larga”	2.2	“to be of large sleeve”
25. “far cadere le braccia”	2.3	“to make the arms fall”
26. “non vedere l’ora”	2.8	“to not see the hour”
27. “perdere la faccia”	2.4	“to lose the face”
28. “stare in campana”	2.1	“to stay in bell”
29. “avere poco sale in zucca”	2.3	“to have few salt in pumpkin”
30. “tendere le orecchie”	2.2	“to stretch the ears”
31. “essere uno stinco di santo”	2.3	“to be a shin bone of a saint”
32. “avere le mani in pasta”	1.8	“to have the hands in dough”
33. “prendere in castagna”	2	“to take in chestnut”
34. “lasciarci le penne”	2.1	“to leave the feathers”
35. “far venire il latte alle ginocchia”	1.9	“to make the milk come to the knees”
36. “essere a piede libero”	2.1	“to be at free foot”
37. “tenere banco”	1.9	“to hold bench”
38. “essere sulla cattiva strada”	2.4	“to be on the bad path”
39. “restare con un palmo di naso”	2	“to remain with a span of nose”
40. “mettersi le gambe in spalla”	1.5	“to put the legs on shoulders”

(IF = idiom familiarity. Some sentences are ungrammatical in English, because some idioms are ungrammatical in Italian).