The neural basis of idiom processing: Neuropsychological, neurophysiological and neuroimaging evidence

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In this paper we review the neuropsychological, neurophysiological and neuroimaging literature on the neural basis of idiom comprehension. We will present the first studies from the seventies to the nineties in 1900, which focused on the role of the right hemisphere only, and then we will move to the more recent research which provides evidence that both hemispheres, especially the left, are involved and that semantic and syntactic analyses are required in order to process idioms. The critical neural structures seem to be the left temporal and the bilateral prefrontal regions. Crucially, we will also show that the patients' selection criteria, the type of task and the type of idiom are relevant variables in determining the results. Finally, we suggest a possible anatomo-functional model in order to explain how idiomatic strings are processed in the brain.

Keywords: neuropsychology, fMRI, rTMS, idiom comprehension, prefrontal cortex, left temporal lobe

1. Introduction

The interdisciplinary study of pragmatics has held that a distinction exists between what speakers say and what they conversationally mean or implicate. Pragmatic aspects of meaning involve the interaction between an expression's context of utterance and the interpretation of elements within that expression. Figurative language allows speakers/writers to communicate meanings that differ in various ways from what they literally say.

Among the most common forms of figurative language are idioms. According to Nunberg et al. (1994), idioms do not form a unitary class but rather vary along a number of syntactic and semantic dimensions. Some idioms have literal meanings that denote concrete things and their relations (*spilling beans*) while others do not (*second thoughts*). Idioms typically involve metaphors (*take the bull by the horns*), metonymies (*lend a hand*), hyperboles (*not worth the paper it's printed on*) or other kinds of figuration, even if speakers may not perceive the figure originally involved (although there are idioms not involving figuration at all, such as *by dint of*). An idiom can be seman-

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tically opaque, when the speaker needs to know the stipulated meaning that cannot be derived either from the image evoked or from the constituent word meanings. Conversely, in transparent idioms there is a close relationship between metaphorical and literal sense. Idioms vary along compositionality, which refers to the degree to which the phrasal meaning, once known, can be analysed in terms of the contribution of the idiom parts. In *spill the beans*, for example, there is a clear correspondence between *spill* and *bean*s and the relevant parts of its figurative meaning 'divulge information'. Idioms also vary in the extent to which they can be syntactically transformed, still retaining their idiomatic meaning (Gibbs & Gonzales 1985). Finally, some idioms do not have any well-formed literal counterpart while others have and are called ambiguous (e.g., *break the ice*).

Early theories of idiom comprehension (e.g., the Idiom List hypothesis) assumed a literal meaning priority and a search for a figurative interpretation only when the literal one was rejected (Bobrow & Bell 1973). Differently, the most influential Lexical Representation hypothesis posited that idioms behave as long, morphologically complex words stored in the mental lexicon together with other lexical units (Swinney & Cutler 1979). Linguistic processing of the string and retrieval of the idiomatic meaning was supposed to proceed in parallel with the second faster than the first. A more extreme version of this hypothesis argues that people do not engage in any linguistic analysis at all and could entirely bypass the literal meaning directly accessing the figurative interpretation (Gibbs 1984). Alternatively, the Configuration hypothesis (Cacciari & Tabossi 1988) suggests that idioms are configurations of words that undergo a linguistic analysis until enough information has accumulated to prompt the recognition of the idiomatic nature of the string and the subsequent activation of the related figurative meaning.

All the above-mentioned hypotheses are based on language-unimpaired participants and assume that, in order to understand an idiom, lexical integrity is required. Therefore, injuries to the left hemisphere (**LH**), typically resulting in aphasic impairments, ought to damage, along with other linguistic skills, patients' ability to comprehend idiomatic expressions. However, at odds with this tenet, a widely accepted view in the neuropsychological research assumes that damage to the LH may have no major consequences, and it is the non-dominant right hemisphere (**RH**) that is important for the processing of idiomatic expressions (Kempler et al. 1999; Van Lancker & Kempler 1987). Based on a double dissociation found in right brain-damaged (**RBD**) and left brain-damaged (**LBD**) patients (poor performance on

idioms and good performance on novel sentences in RBD patients vs. good performance on idioms and poor performance on novel sentences in LBD patients), Kempler et al. (1999) stated that the RH is preferentially involved in processing figurative language in healthy adults, suggesting that literal and idiomatic language are mediated by different cerebral structures. These neuropsychological findings indirectly suggest that familiar phrases are processed by the RH like unitary, non-syntactically analysed elements. According to this view, the meaning of an idiom is directly (and holistically) retrieved from memory. In Kempler et al.'s opinion, this "familiar-phrase-as-single-word" hypothesis, which considers that familiar phrases behave formally (structurally), but not semantically, like words, is compatible with the Lexical Representation hypothesis.

An attempt to accommodate contrasting data on figurative language lateralization in general is provided by Giora (1997; 2007). The Graded Salience Hypothesis (**GSH**) suggests that the degree of meaning salience of the linguistic stimuli determines the order and the extent by which meanings are processed, regardless of figurativity. A meaning is salient if it is coded and has marked prominence due to factors such as conventionality, frequency, familiarity, and prototypicality. Salient meanings, of course, are easier to access than less salient ones, regardless of literality. The GSH predicts stronger RH involvement in the comprehension of non-salient (literal) meanings of idiomatic expressions and stronger LH involvement in the comprehension of their salient (idiomatic) meanings (Giora 2003). Alternatively, and specifically for idioms, Huber-Okrainec et al. (2005) have proposed, by examining children with callosal agenesia, that interpreting idioms requires inter-hemispheric integration. The corpus callosum, therefore, would mediate interhemispheric interactions especially during idiom comprehension development.

As a general point, models that are based on tasks or classes of task will have limited explanatory value outside the immediate cognitive domain of those tasks. Therefore, comparison between studies is not straightforward in many cases because of variations in tasks and methods and only converging evidence using different methodologies and tasks would strengthen the results concerning the respective role of the left and right hemisphere in idiomatic language processing. What we assume is that no single experiment is definitive, but a sufficiently rich and coherent body of data will place major constraints to rule out alternative hypotheses. In this paper we present a review of our experimental studies focused on idiom comprehension, which were aimed at identifying the anatomical structures involved in idiom

processing and at integrating the results in the current models of idiom comprehension. More specifically, we will present evidence that idiom comprehension involves the same areas engaged by literal language processing and that the additional requirements of idiomatic processing involve prefrontal areas. We will divide this review in two sections. First, we will present data from neuropsychological studies on focal brain-damaged patients. Then, we will show evidence of the anatomical correlates of idiom processing as found in repetitive transcranial magnetic stimulation (rTMS) and functional magnetic resonance imaging (fMRI) studies.

2. Neuropsychological evidence

An overview of the neuropsychological studies that will be described in the following subsections is provided in Tab. 1.

2.1. Historical notes on the Right Hemisphere Hypothesis

In a 'neglected' paper on figurative language, Stachowiak et al. (1977) investigated the semantic and pragmatic strategies in the comprehension of spoken texts in four subgroups of aphasic patients, in normal controls and RBD patients. Short texts of similar linguistic structure were read to the participants, who were required to choose the appropriate picture for the story from a multiple choice set of five. Besides a picture showing the main event of the story, one picture depicted the literal sense of a metaphorical comment, and the others misrepresented semantic functions (subject noun phrase, verb, verb complement phrase) expressed in the text. Half of the stories were commented with transparent idioms and half with opaque idioms. Apparently, performance of the aphasic groups (19 Broca's, 19 Wernicke's, 19 amnestic and 19 global aphasics) was not poorer than that of the other two groups, being better for opaque idioms for all. Nevertheless, Wernicke's aphasics showed difficulties in dealing with metaphorical idioms and most frequently pointed to the picture representing the literal interpretation. With opaque idioms, literal responses decreased. Possibly, aphasics relied more heavily on the pictorial aspects of contextualization and therefore they did not differ from controls. Whether or not aphasic patients had difficulty in comprehending metaphorical idioms isolated from verbal and pictorial context was not investigated. However, it is possible that if a particular word or sentence structure within a text is

Table 1. Neuropsychological studies on idioms.

	Patients	Stimuli	Task	RH	LH	Limitations
Winner & Gardner 1977	20 RBD 32 LBD	18 *metaphors*	Offline: 1. picture matching 2. oral definition	+ -	-/+ +	Misquoted
Stackowiak et al. 1977	19 RBD 76 LBD	13 opaque 13 transparent	Offline: picture matching (after a story)	-/+ -	- +	Idioms not tested in isolation
Van Lancker & Kempler 1987	11 RBD 28 LBD	20 *mixed* (idioms+formulaic language)	Offline: picture matching	+	-	Mixed stimuli, no information on patients
Tompkins et al. 1992	20 RBD 20 LBD	11 transparent	Online: word monitoring Offline: oral definition	- +	- +	Only 65% of LBD were aphasic
Kempler et al. 1999	16 RBD 25 LBD	20 *mixed*	Offline: picture matching	+	-	Mixed stimuli, no information on patients
Nenonen et al. 2002	1 LBD	45 verb phrase 148 noun phrase	Offline: reading aloud Online: cross-modal priming	NT	+ (VP)	No details on lesion site
Hillert 2004	1 RBD 2 LBD	16 noun phrase	Online: cross-modal lexical decision	+	-	No information on patients
Papagno et al. 2004	10 LBD	34 NA	Offline: 1. picture matching 2. oral definition	NT	+	Offline tasks
Papagno & Genoni 2004	11 LBD	40 NA	Offline: picture matching	NT	+	Offline task
Papagno et al. 2006	15 RBD 12 LBD	40 NA	Offline: 1. picture matching 2. oral definition	+ (F) - (NF)	+	Offline tasks
Cacciari et al. 2006	15 LBD	23 A	Offline: word matching	NT	+	Offline task
Papagno & Caporali 2007	15 LBD	40 NA, 15 A	Offline: 1.word matching 2. picture matching 3. oral definition	NT	+	Offline tasks
Bélanger et al. 2009	5 RBD 6 LBD	32 A (in context)	Offline: prosodic production	-	+	Testing production

List of abbreviations: RH = right hemisphere, LH = left hemisphere, RBD = right brain-damaged, LBD = left brain-damaged, NT = not tested, NA = unambiguous, A = ambiguous, VP = verb phrase, F = frontal, NF = non frontal, + = impaired, - = unimpaired.

not understood, there are enough contextual cues that allow inferring the missing part. Thus, the verbal redundancy can make up for the difficulties on the word and sentence levels and one could expect a worse performance when aphasics are presented with idioms out of context.

This study is almost never mentioned, and the RH is considered crucial in idiom comprehension on the basis of a double dissociation between familiar (figurative) language and novel (literal) language reported by Van Lancker & Kempler (1987). However, in this study, items were not chosen on the basis of their intrinsic (transparency/opacity, decomposability, etc.) features, and 20 items, including idioms, proverbs and courtesy phrases, such as *I'll get back to you later*, were considered together as 'familiar language'. Finally, the presence of additional neuropsychological (attentional, perceptual, spatial) deficits was not tested (or reported). This last point is especially relevant, because sensory and cognitive deficits associated with RH damage might impair processing of critical elements or deplete available resources for further analysis, thus leading patients to resort to the less demanding choice (the literal alternative, which exactly corresponds to the sentence) in a sentence-to-picture matching task. Picture complexity is higher for idiomatic than for literal sentences. Literal sentences allow a single interpretation, and limited visuo-spatial and attentional resources could still be sufficient to allow a correct response. Indeed, RBD patients with neglect show a significant correlation between idiom comprehension performance (when tested with a sentence-to-picture matching paradigm) and star cancellation or line bisection accuracy (Papagno et al. 2006). Finally, in Van Lancker & Kempler (1987)'s study, aphasic patients' performance is considered to be normal for familiar phrases, but the mean percentage of correct responses was 72%, which suggests a (mildly) impaired performance, at least as compared to control subjects' mean percentage of 97.3%.

2.2. Challenging the Right Hemisphere Hypothesis: Studies on aphasic patients

Given all these pitfalls, we investigated whether the comprehension of idiomatic sentences of ten LBD aphasic patients with semantic deficits, was actually good, as claimed by the RH hypothesis, or impaired as follows from current psycholinguistic models of the mental representation and processing of idioms (Papagno et al. 2004). We selected 34 familiar verbal unambiguous idioms. For each idiomatic

expression three line drawing pictures were created: one representing the idiomatic meaning, one representing as well as possible the literal interpretation, one representing an unrelated situation. The idiom was presented without context, in a simple syntactic form (subject followed by the idiomatic string). The performance as reflected in the picture-to-sentence matching task was severely impaired in all our patients as compared to age- and education-matched controls. This impairment was well beyond their difficulty in understanding the individual words occurring in the string, as patients' comprehension of individual words was much better than their comprehension of the idiomatic expressions in which they occur. The comprehension of idioms was also impaired relative to literal expressions, which were also tested, suggesting that idioms offer a specific difficulty. Patients did not choose at random, as they selected the unrelated alternative only few times, producing a number of errors entirely comparable with that of the healthy participants. Rather, they produced a disproportionate number of literal errors, in spite of the fact that the instructions made it clear that the stimuli were idiomatic, non-literal sentences. Patients' literal errors did not correlate with plausibility. Although plausibility does not seem to explain patients' performance, nevertheless they showed a strong bias towards the literal interpretation and this bias might have prevented them from choosing the figurative alternative, even when they knew the idiomatic meaning. Prior to any attempt to interpret this bias, we assessed patients' ability at comprehending the same idioms by asking them to give a verbal explanation. We clearly explained that meanings would have to be the figurative ones. Mimics and partial explanations were also accepted. Patients still produced significantly fewer correct responses than controls, but in this case there were significantly more non-literal than literal errors, reflecting the incomprehension of the strings as well as the difficulty at expressing the meaning of known expressions. Therefore, these results failed to corroborate the Right Hemisphere Hypothesis.

The dichotomy between LH and RH derives from a sharp distinction between literal and non-literal language and the RH is viewed as equally engaged in the processing of all sorts of non-strictly denotative linguistic materials, including prosodic cues (typically carrying emotional as well as linguistic information), metaphors, idioms, proverbs and different types of speech acts (Burgess & Chiarello 1996). However, on the one hand the distinction between figurative and non-figurative language is neither clear nor theoretically unchallenged; on the other hand, various figurative forms are likely to call for different

comprehension processes and the involvement of the RH in all these processes is still to be established.

2.3. The role of suppression, syntax and semantic memory

While concurring in showing the difficulty in the comprehension of idioms, matching an idiom to the corresponding picture is more demanding than providing an oral explanation of it, corroborating the view that patients had a better idiomatic comprehension than reflected in the string-to-picture matching task. In the Papagno et al. (2004)'s study, there were about 13 idioms that, although known to the patients, were interpreted literally in the string-to-picture matching task. A possible explanation is in terms of suppression mechanisms. Suppression plays a crucial role in many aspects of language comprehension (Gernsbacher & Robertson 1999): it is 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; other times this information is activated internally as when we have to deal with the competing meanings of a word or phrase. Suppression is likely to be mediated by the central executive, which allocates attentional resources to different simultaneous tasks. In the case of aphasic patients, language processing resources are damaged, possibly resulting in a greater involvement of the central executive to accomplish the linguistic task, which depletes the attentional pool, and prevents the appropriate suppression of the literal meaning. Suppression failed in almost half of the trials, suggesting that some factor was guiding the choice in the remaining half. A careful scrutiny of the patients' responses suggested that they might have relied on syntactic information: a syntactically ill-formed sentence may have cued them not to accept its literal interpretation and to search for a non-literal alternative. According to this hypothesis, Papagno et al. (2004) found that syntactically inappropriate idioms gave rise to more correct responses and patients with a preserved performance on grammatical judgments took advantage of syntactic information, whereas patients with poor syntactic competence made significantly more errors on this ill-formed idioms. On top of that, we reasoned that patients with semantic memory deficits, who are likely to rely on syntactic cues to reject the literal interpretation of idiomatic expressions, should perform differently from agrammatic patients who should be able instead to rely on plausibility, while disregarding information concerning the syntactic form of the idiomatic expressions.

This is precisely what we tested in a further experiment on 11 aphasic patients with normal semantic memory and a variable degree of syntactic impairment (Papagno & Genoni 2004). Patients were submitted to the same task previously described. They also performed a grammaticality judgment task on both idioms and literal sentences. Idiom comprehension was impaired, again with a bias toward the literal interpretation. Performance on idioms correlated with performance on literal sentence comprehension, implausibility of the literal interpretation, syntactic competence, and with the patients' ability to recognize whether idioms were presented in their syntactically correct form or not.

Three main conclusions can be drawn from these experiments: first, LH damage impairs comprehension of unambiguous idioms. Second, aphasic patients make use of spared language abilities in order to comprehend idiomatic expressions: syntactic competence when lexical-semantic knowledge is impaired, lexical-semantic knowledge when syntactic analysis is defective. Third, if idioms were just long words, as suggested by the Lexical Representation hypothesis, patients with no lexical-semantic deficits, but with syntactic impairment, should comprehend them easily, which is not the case.

2.4. Idiom types: Ambiguous versus unambiguous idioms

So far we have reported patients' performance with unambiguous idioms, but it is possible that idioms selected on the basis of a different dimension could produce a different pattern. Indeed, Nenonen et al. (2002) showed that not all idiomatic expressions are processed alike. The authors compared reading of Finnish verb phrase idioms and noun phrase idioms in a deep dyslexic patient: on the basis of a series of experiments, they concluded that noun phrase idioms are processed more holistically than verb phrase idioms, which were processed in the same way as control literal sentences, with the appearance of morphological errors in the verb.

Although there is evidence of impairment of idiomatic processing in aphasia, some aphasic patients show a normal performance (Hillert 2004), as it is the case of two German LBD patients, one with Wernicke's and the other with global aphasia tested with a cross-modal lexical priming paradigm: this result, however, does not contradict what previously reported, since stimuli were German noun compounds, which can have both idiomatic and literal meanings. Indeed, noun phrase idioms have proved to be easier to access than

verb phrase idioms, which are the most frequently used form of idiomatic expressions in studies on aphasic patients.

To sum up, aphasic patients are impaired with verbal unambiguous idioms. There are, however, two main issues. The first is the type of task and will be discussed in the following section. The second point is that RBD patients were not directly compared to LBD aphasic patients. However, when this comparison is performed, it appears that aphasic patients are significantly worse (Papagno et al. 2006) and RBD performance correlates, as expected, with visuo-spatial abilities. There is also a significant difference in performance between frontal and non-frontal RBD patients in idiom comprehension, with non-frontal patients performing as well as controls and frontal RBD as aphasic patients with a temporal lesion.

In accordance with the GSH, aphasic patients showed that a left temporal lesion is associated with a literal interpretation of the sentence: following this hypothesis, when the LH (but not the RH) is damaged, the literal (less salient) interpretation is activated and produced by the patient. When the right prefrontal lobe is damaged, the non-salient literal interpretation is not inhibited and the performance is similar to that of aphasic patients.

Up to now, we have considered a specific group of idioms, namely unambiguous idioms. A further step would be to verify whether these results can be extended to other class of idioms, as ambiguous idioms. In this case, we used a different testing modality, the word-to-sentence matching task, since we have demonstrated that it is an easier task than the picture-to-sentence matching task (Cacciari et al. 2006). Syntactically simple sentences paired with four words were presented and the task was to choose the one that corresponded to the figurative meaning. The four words were matched in terms of length and written frequency: the target word corresponded to the idiomatic interpretation of the string (e.g., *wine*, for 'alzare il gomito', literally *to raise the elbow*, meaning to drink too much); one foil was semantically associated with the last constituent word of the idiom string (in the previous example, *leg*); and two words were unrelated foils (*tree*, *box*). Specifically, the first type of unrelated target was either an abstract or a concrete word depending on the nature of the idiomatic target. A target word was considered as concrete based on the availability of the word referent to sensory experience. Concreteness values were obtained from a database for 626 Italian words (Burani et al. 2001). The second type of unrelated target was a word that could plausibly complete the verb in the verb phrase (*box*). The rationale whereby we selected these four types of targets was the following: the choice of

the idiomatic target should reflect the knowledge and availability of the idiomatic meaning of the idiom string. The choice of the semantically associate foil might reflect an attempt at interpreting the string literally when the patient does not know the idiom meaning, or, alternatively, is unable to access the idiomatic interpretation of the idiom string. The semantic associate foil, however, does not reflect the literal meaning of the sentence and its choice is clearly an error. The two unrelated foils should signal an impaired performance of both the idiomatic and the literal processing of the string.

Aphasic patients were significantly more impaired in idiom comprehension than matched controls, even with ambiguous expressions. Semantically associate errors were indeed significantly more frequent than unrelated errors. Two explanations might be provided: the first relies on the idea that in aphasic patients what might be deficient is the idiom recognition mechanism. Alternatively, semantically associate errors reflect impairment in inhibiting the word meaning associated to the final constituent word of the idiom string or a faster activation of that meaning. If this were the case, then the retrieval of the figurative meaning would be blocked by a sort of processing loop in which the patient is unable to get rid of the literal meaning of the string. It could also be possible that the choice of the semantically related target only reflects a lexical association with the last word of the string, without a global processing at a sentential level. However, previous evidence on the comprehension of idioms in brain-damaged patients suggests that their impairment extends far beyond a single-word level.

Finally, we compared the performance of 15 aphasic patients on ambiguous versus unambiguous idiom (matched for familiarity and length) comprehension using the sentence-to-word matching task (Papagno & Caporali 2007). The difference was not significant. However, the type of error produced was not the same. More unrelated errors preserving the semantic class (abstract foil if the meaning of the idiom was abstract and concrete if it was concrete) for unambiguous idioms and significantly more literal errors for ambiguous idioms were found. In addition, two patients showed a double dissociation: while one was severely impaired on comprehension of ambiguous idioms but gave a noticeably better performance on unambiguous idioms, the other made no errors on ambiguous idioms and performed at chance with unambiguous.

Giora & Fein (1999) suggested that hearing familiar idioms should lead to both idiomatic and literal meaning being activated, because both interpretations are salient outside of context. We pro-

pose that in the case of unambiguous idioms, the literal meaning is less salient, and therefore can be easily rejected unless it is overtly suggested, as in the sentence-to-picture matching task. On the contrary, we can assume that the literal meaning is retained in the case of ambiguous sentences, requiring a more relevant role of executive functions.

2.5. Task type and context

The effect of task has been emphasised first by Tompkins et al. (1992) who found no impairment in LBD (though only 65% were aphasics) and RBD patients when an online task was used, but both groups performed worse than controls when they were submitted to an oral definition (offline) task. Since the nature of the task has proved to be relevant, we further analyzed this aspect by means of a series of new experiments (Papagno & Caporali 2007). Fifteen aphasic patients were submitted to three tasks of unambiguous idiom comprehension: a sentence-to-picture matching, a sentence-to-word matching and an oral definition task. A high variability emerged among aphasic patients, some of whom were severely impaired, while others performed at parity with the control group. Overall, the results of all tasks showed that idiom comprehension in aphasic patients was impaired with respect to that of the control group, and was significantly affected by the type of task. The type of task had no effect on healthy subjects' performance. The performance was not exclusively related to the severity of the language deficit, except in the case of oral definition, which could not be performed in severe non-fluent patients. The overt representation of the literal meaning, namely a bizarre picture corresponding to some form of literal interpretation, had a strong interference effect, similar to the Stroop effect. Patients are unable to suppress the literal interpretation when its explicit pictorial representation is available; this suggests that the literal interpretation somehow remains active while the sentence is being processed, even when its plausibility is very low. In the sentence-to-picture matching task, both patients and controls very rarely chose the picture corresponding to a so-called "single word" option (e.g., in the case of *to come to the hand*, meaning *to fight*, this alternative was a picture representing a boy lifting his hand, the word *hand* being the key word of the idiom). This type of error occurred with the same frequency as the unrelated error, suggesting that some level of processing of the sentential literal meaning took place and that the patients' choice was not influenced only by a lexical effect. The sentence-to-

word matching task, with no literal alternatives but with a semantic foil (in the previous example *finger*), reduced the interference of the literal interpretation, but unrelated errors were still present, indicating a genuine lack of knowledge of the idiomatic meaning. Since literal errors appeared especially when the literal interpretation was overtly 'offered' to the patient, it could be possible that the figurative meaning is lost (or not accessed) and, when the literal alternative is lacking, an unrelated error, preserving the abstract/concrete nature of the target, is produced. This is a further demonstration that the patient tries to analyse the whole sentence and does not process a single word only.

Recently, it has been shown that prosodic realization influences how idioms are interpreted. Prosody seems relevant when idioms are embedded in an idiomatic or literal biasing context and presented in a manner such that the interpretative contrast is highlighted (Baum & Titone 2005; Bélanger et al. 2009). The fact that in our tasks idioms were presented in a neutral voice and out of context minimized the role of prosody and context in comprehension, and therefore aphasic patients could not benefit from contextual cues, in contrast with Stachowiak et al. (1977)'s patients. Yet, there is supporting evidence that context is a relevant factor in idiom comprehension: if a particular word or sentence structure within a text is not understood, cues in the context help to infer the missing part. This can account for the clinical experience that some aphasic patients are surprisingly well able to follow conversational topics familiar to them. Moreover, it has been shown that populations who experience difficulties processing language in context often have poor idiom understanding, and the presence of a supportive context boosts younger and older children's comprehension of idioms. Indeed, inference from context might aid the acquisition of idiom meanings (Cain & Towse 2008), and pragmatic comprehension is seen as an ability to utilize context in comprehension.

In conclusion, aphasic patients are impaired in both ambiguous and unambiguous idiom comprehension when they are presented out of context. They can, however, benefit from contextual cues, improving their performance. RBD patients are impaired when the lesion involves the prefrontal lobe. Therefore, it is possible that the LH is involved in the interpretation of single elements within the expression, while the RH (and more specifically the prefrontal cortex) is responsible for the activation of contextual cues (see for example Simons et al. 2005). The prefrontal cortex can have different roles in idiom comprehension, which are better addressed with neurophysiological and neuroimaging studies.

3. Neurophysiological and neuroimaging evidence

3.1. TMS evidence

A general analysis of the lesions shows two relevant sites for the patients' performance on idiom comprehension: a frontal and a temporal region, the latter being constantly involved when unambiguous idiom are concerned. Pursuing the aim of linking idiomatic processing to defined neural correlates, the use of rTMS allowed adding a piece of information: whereas neuropsychological studies only show a correlation between an impaired function and a lesion, being an interference technique, TMS suggests a causal relationship. Indeed, we confirmed neuropsychological results through several rTMS experiments using both off-line (Oliveri et al. 2004) and on-line paradigms (Fogliata et al. 2007; Rizzo et al. 2007) and a sentence-to-picture matching task.

rTMS experiments corroborated the data on brain-damaged patients (a right prefrontal lesion produces the same degree of impairment found in aphasics), showing an increased number of errors and reduced reaction times after stimulation of both right and left BA 9 (Rizzo et al. 2007). A faster response with less accuracy suggests a release from inhibition. The finding of a role of the right (beyond the left) dorsolateral prefrontal cortex could explain why figurative (and idiomatic, in particular) language impairment has been considered a consequence of a RH damage: the lesion site could well have been in the prefrontal region. Frontal regions could be involved for two reasons: once the sentence is linguistically analysed, producing two possible interpretations, the literal and the figurative, a response must be selected. This requires a selection process and a response monitoring; selection and monitoring of internally generated responses are likely to be performed by the central executive, whose neural correlates are supposed to be in the prefrontal lobe. Indeed, patients with prefrontal lesions produce a higher number of literal interpretations as compared to patients with non-frontal lesions. The bias towards the literal interpretation can be found with different tasks, such as oral definition (Papagno & Vallar 2001; Papagno et al. 2003), and with a priming paradigm (Titone et al. 2002) or a decision on whether or not a sentence matched a picture in schizophrenia (Schettino et al. 2010), with literally plausible idioms. Therefore, it cannot be ascribed only to the nature of the task. Two functions can account for the prefrontal involvement: either retrieving/activating the figurative meaning or inhibiting the literal one. The two hypotheses were tested by means of rTMS: if the prefrontal cortex is involved in retrieving/activating the

idiomatic meaning from semantic memory, rTMS effects on the temporal and frontal sites would be effective at the same time, or possibly first in the prefrontal cortex; conversely, if the prefrontal cortex is involved in suppressing/inhibiting the literal meaning, the effect of the prefrontal stimulation should persist at later stages when the stimulation of the temporal site has become ineffective. In a study which explored the temporal dynamics of left prefrontal and temporal cortex in idiom processing by using on-line rTMS in healthy participants, a selective decrease in accuracy was found for idioms when rTMS was applied to the prefrontal (BA 9) and temporal (BA 22) cortex 80 ms after picture presentation. Moreover, rTMS to the prefrontal cortex, but not to the temporal cortex, continued to affect the performance with idiomatic sentences at 120 ms. The results seem to suggest that the prefrontal region is involved in both the retrieval of the figurative meaning from semantic memory and the monitoring of the response by inhibiting alternative interpretations (Fogliata et al. 2007).

3.2. fMRI evidence

A bilateral prefrontal involvement has been confirmed also by fMRI activation studies that have used different paradigms, such as deciding whether or not the meaning of a sentence, either literal or idiomatic, matched a picture (Romero Lauro et al. 2008), or whether or not a word was related with a previously visually presented (either idiomatic or literal) sentence (Zempleni et al. 2007). Making judgments about literal and non-literal sentences yielded a common network of cortical activity, involving language areas in the LH. However, the non-literal task elicited overall greater activation, both in terms of magnitude and spatial extent. An activation of the temporal cortex was found, as predicted by neuropsychological and rTMS studies. In addition, the left superior frontal (approximately covering BA 9), as well as the left inferior frontal gyrus, were specifically involved in processing idiomatic sentences. Activations were also seen in the right superior and middle temporal gyri, in the temporal pole, and in the right inferior frontal gyrus.

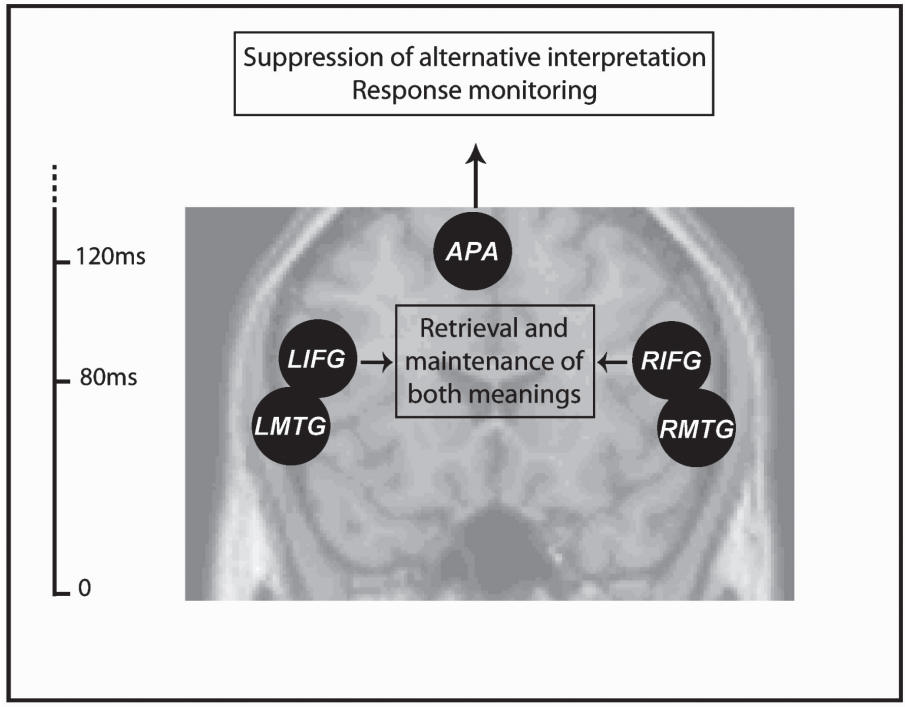
The fMRI studies reported above investigated Dutch and Italian idioms processing. A further fMRI study confirmed this network of activations with Hebrew idioms. Mashal et al. (2008) examined the role of the left and right hemispheres in processing alternative meanings of ambiguous idiomatic sentences in a behavioral and in an fMRI study. The fMRI data showed that when literal interpretations of idioms were processed, neural activity increased in right lateralized brain regions,

including the posterior middle temporal gyrus. More activation was found in areas of the LH, including the inferior frontal gyrus, when participants processed the salient idiomatic meanings of ambiguous idioms than when they processed their non-salient, literal meanings. Based on the GSH, which predicts that non-salient interpretations will be processed in the RH while salient meanings will primarily engage the LH, it was predicted that processing the non-salient (plausible) literal interpretations of idioms would recruit RH regions, whereas processing salient meanings, accessing the idiomatic meanings of idioms or the literal interpretations of conventional literal sentences will mainly activate the LH. The results provided evidence for RH advantage in processing literal, non-salient interpretations of idioms with plausible literal meanings. Behavioral (visual field) and fMRI data showed that RH is sensitive to non-salient linguistic interpretations and that literal interpretations of idioms are accessed faster than their idiomatic meanings only in the RH. The fMRI data showed that processing salient meanings (the idiomatic meaning of idioms and the literal interpretations of literal sentences) involved LH regions. This is totally consistent with the lesion data on aphasic patients showing that a left temporal lesion is associated with a literal interpretation of the sentence: following this hypothesis, when the LH *is* damaged, the literal (less salient) interpretation is activated (in the RH) and therefore produced. Finally, Hillert & Buracas (2009), in a sentence decision task, found a left-sided preference of activation in the superior and middle frontal gyrus, slightly different for ambiguous and unambiguous idioms.

4. A model of idiomatic processing

To sum up, there is not a RH prevalence, but a bilateral (especially left) prefrontal and temporal involvement is required in order to process idiomatic sentences. Converging evidence suggests that the prefrontal region might eventually retrieve the figurative meaning and inhibit the alternative literal interpretation. Merging together neuropsychological, neuroimaging and neurophysiological data, we suggest the following model: the idiomatic sentence is linguistically analyzed, producing two possible interpretations, that are matched with the context and one or the other is accepted (or both may be rejected). Retrieving the figurative meaning from semantic memory and maintaining the two interpretations involves a simultaneous temporal and prefrontal activation, with the prefrontal activation lasting longer than the temporal one to provide response monitoring (see Fig. 1).

Figure 1. Schematic representation of idiom processing.



Black dots on a coronal section of the brain roughly represent the network: LMTG = left middle temporal gyrus; RMTG = right middle temporal gyrus; LIFG = left inferior frontal gyrus; RIFG = right inferior frontal gyrus; APA = anterior prefrontal area (BA9). When an idiomatic sentence is encountered, the linguistic analysis produces two possible interpretations: idiomatic and figurative. LIFG and RIFG retrieve both meanings from semantic memory (LMTG and RMTG) and maintain them, until bilateral (left>right) APA (BA 9) selects the appropriate meaning, suppressing the alternative and monitoring the response. On the left side of the figure the temporal dynamics of prefrontal and temporal activation are reported: temporal and prefrontal areas are involved simultaneously (80 ms after picture presentation), whereas BA9 remains active on a later stage (120 ms).

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