

IDIOM COMPREHENSION: A PREFRONTAL TASK?

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Abstract

We investigated the neural correlates of idiomatic sentence processing using event-related functional magnetic resonance imaging. Twenty-two healthy subjects were presented with 62 literal sentences and 62 idiomatic sentences, each followed by a picture, and were required to judge whether the sentence matched the picture or not. A common network of cortical activity was engaged by both conditions, with the nonliteral task eliciting overall greater activation, both in terms of magnitude and spatial extent. The network that was specifically activated by the non-literal condition involved the left temporal cortex, the left superior medial frontal gyrus (Brodmann area 9), and the left inferior frontal gyrus. Activations were also present in the right superior and middle temporal gyrus and temporal pole and in the right inferior frontal gyrus. In contrast, literal sentences selectively activated the left inferior parietal lobule and the right supramarginal gyrus. An analysis of effective connectivity indicated that the medial prefrontal area significantly increased the connection between frontotemporal areas bilaterally during idiomatic processing. Overall, the present findings indicate a crucial role of the prefrontal cortex in idiom comprehension, which could reflect the selection between alternative sentence meanings.

Introduction

While the crucial role of the left hemisphere (LH) in language function is undisputed, several aspects of linguistic processing have been attributed to the right hemisphere (RH). In particular, a crucial role has been attributed to the right hemisphere in figurative language processing. Figurative language allows speakers to communicate meanings that differ in various ways from what they literally say. There are several forms of figurative language. These include metaphors, where ideas from dissimilar knowledge domains are either explicitly (my love is like a red rose) or implicitly (our marriage is a roller-coaster ride) compared; idioms, where a speaker's meaning cannot be derived from an analysis of the words' typical meanings (to kick the bucket); proverbs, where speakers express widely held moral beliefs or social norms; irony, where a speaker's meaning is usually the opposite of what is said; hyperbole, where the speaker exaggerates the reality of some situation (I have ten thousand things to do) etc (for a detailed lists of different forms of figurative language see Gibbs 1999). Data concerning the role of the RH in figurative language comprehension have been obtained originally from neuropsychological studies, which often did not distinguish among different forms of figurative language, even if it is not known whether the same processes and networks are involved in their interpretation. For example, Winner and Gardner (1977) found that aphasic left brain damaged (LBD) patients were able to perform correctly when they had to associate metaphoric expressions with the corresponding picture, while right brain damaged (RBD) patients, despite being able to give correct verbal explanations, chose the picture corresponding to the literal meaning. While this finding has been taken as evidence that RBD patients are impaired in figurative language, it may only indicate that RBD patients are defective in

picture-matching (Papagno and Caporali 2007).

More recently neuropsychological evidence has accumulated against a unique role of the RH in figurative language. The majority of studies has been concentrated on metaphors. No significant difference has been found between RBD patients and healthy participants in metaphor comprehension (Giora and others 2000), but rather a significant disadvantage of LBD patients relative to both RBD patients and controls. More specifically, significant negative correlations were found between metaphor comprehension and damage to the left middle temporal gyrus and to the junctional area of the superior temporal and supramarginal gyri.

Additional studies with different methodologies (e.g. priming) that initially supported the RH hypothesis, have recently questioned a strict dichotomy of the roles of the two hemispheres in figurative language processing (Burgess and Chiarello 1996). For instance, an investigation of semantic priming for literal and metaphoric associates presented to either the left or the right visual field showed priming effects for metaphorically related targets for the left visual field, while literally related targets were primed solely for the right visual field (Anaki and others 1998); on the other hand, two more recent divided visual field priming experiments (Kacinik and Chiarello 2006) have shown that processes in both hemispheres can support metaphor comprehension.

Contrasting results are also provided by using functional imaging, such as PET (Bottini and others 1994) and fMRI (Rapp and others 2004). In the former PET study, a RH role is reported, although activation of both RH and LH regions was seen when only six normal subjects decided whether or not a sentence was plausible as a metaphor. On the other hand, the latter fMRI experiment using a different task (reading metaphors in contrast to literal sentences)

revealed significant activations in the left lateral inferior frontal (BA 45/47), inferior temporal (BA 20) and posterior middle/inferior temporal (BA 37) gyri (Rapp and others 2004). Similar results have been obtained with subjects deciding whether two out of three auditorily-presented adjectives had a similar meaning (Lee and Dapretto 2006). One condition required accessing the literal meaning of the middle word (hot-cold-chilly), whereas the other condition required accessing its metaphorical meaning (hot-cold-unfriendly).

Another form of figurative language, namely idioms, has also been proposed to depend on the RH. Idioms are not a unitary class, as they differ according to a variety of features, such as literality (whether or not they also have a literal meaning), compositionality (whether or not the constituent words can be mapped directly on their idiomatic referents), and opacity/transparency (whether or not the meaning can be derived from the image evoked) (Glucksberg and others 1993).

In the earliest neuropsychological literature, as already pointed out, metaphors and idioms were considered together, as well as so-called “familiar phrases”, including courtesy phrases or formulae (Kempler and others 1999; Van Lancker and Kempler 1987). Based on a double dissociation found in RBD and 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 and others (1999) stated that the RH is preferentially involved in processing figurative language in normal healthy adults, suggesting that literal and idiomatic language are mediated by different cerebral structures. These neuropsychological findings indirectly suggest that familiar phrases are processed like unitary, non-syntactically analysed elements, a process which is sub-served by the RH.

According to this view, the meaning of an idiom is directly (and holistically) retrieved from memory. In the authors' opinion, this "familiar-phrase-as-single-word" hypothesis, which considers that familiar phrases behave formally (structurally), but not semantically, like words, is compatible with Swinney and Cutler's *Lexical Representation hypothesis*, which posits that idioms behave as long, morphologically complex words stored in the mental lexicon together with the other lexical units (Swinney and Cutler 1979). According to this view, the linguistic processing of the string and the retrieval of the idiomatic meaning proceed in parallel, with the second process being faster than the first. An extreme version of this hypothesis (Gibbs 1984) suggests that people do not engage in any linguistic analysis at all, entirely bypassing the literal meaning and directly accessing the figurative interpretation of the idiom string.

As in the case of metaphors, more recent neuropsychological studies, which test separately different aspects of figurative language, have provided data against a specific role of the RH in idiom comprehension (Nenonen and others 2002; Papagno and others 2004; Cacciari and others 2006). Nenonen and others (2002) examined verb and noun phrase idiom reading in a deep dyslexic and found that verb phrase idioms were read as poorly as comparable free phrases. Other studies on aphasic patients with semantic deficits have found a severe impairment in a sentence-to-picture-matching task using non-ambiguous idioms with a significant bias towards the literal interpretation (Papagno and others 2004). Aphasics were impaired even on ambiguous idioms, when a sentence-to-word matching task was used (Cacciari and others 2006). Converging results come also from functional imaging. Zempleni and others (2007) found a common activation of the language network when the processing of idioms was compared to literal sentence interpretation; in

addition, idiomatic processing engaged the inferior frontal gyri bilaterally, as well as the left middle temporal gyrus.

Additional evidence of the LH involvement is provided by repetitive transcranial magnetic stimulation, (rTMS) studies in normals. TMS studies of idioms attempted to integrate anatomical results with the current psycholinguistic models of figurative language interpretation (Oliveri and others 2004). Using an offline paradigm, rTMS applied over left, but not right, BA 22 increased reaction times (RTs) and reduced accuracy, with no difference between literal and nonliteral sentences. These findings, suggesting that a syntactic analysis takes place during idiom comprehension and that the same anatomical regions are involved in idiom and literal sentence comprehension, support the *Configurational Hypothesis* (Cacciari and Tabossi 1988), according to which the individual components of the idiom are analyzed as normal linguistic items until a key part is processed that prompts recognition of the idiomatic nature of the string and activation of its figurative meaning. In another rTMS study, which used an online paradigm, Rizzo and others (2007) found that both the right and the left dorsolateral prefrontal cortex (DLPFC) are involved in monitoring the response in the case of idiomatic sentences. An interference with the activity of this region produced a decrease in accuracy, with a significant increase of literal errors.

An attempt to accommodate contrasting data on figurative language lateralization in general is provided by Giora (Giora 1997; Giora and others 2000). The *Graded Salience Hypothesis* suggests that salient meanings are processed in the LH, regardless of figurativity, while nonsalient meanings, involving distant semantic relationships, are processed in the RH. Alternatively, and specifically for idioms, Huber-Okraimec, Blaser, and Dennis (Huber-

Okraïnec and others 2005) have proposed, by examining children with callosal agenesis, 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. Indeed, comparison between studies is not straightforward in many cases because of variations in tasks and methods. The effect of methodology has already been underlined in an fMRI study on phonological short-term memory (STM) (Logie and others 2003). A significant interaction between response type and the brain regional activation during semantic memory tasks has also been demonstrated (Jennings and others 1997). In the case of patients, besides the effects of the type of task and the measures employed (Papagno and Caporali 2007), re-organization processes and compensatory strategies in the chronic phase cannot be totally excluded.

Therefore 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 the present paper we aim at identifying the anatomical structures involved in idiom processing using fMRI and at integrating our results in the current models of idiom comprehension in order to add further evidence to support one of the two alternative explanations (e.g. lexical hypothesis vs configurational hypothesis). Cognitive psychology studies as well as neuropsychological findings seem to dismiss the possibility that idioms are

treated as long, morphologically-complex words (Peterson and others 2001; Papagno and Genoni 2004). More specifically, we expect that idiom comprehension involves the same areas engaged by literal language processing, as proposed by Oliveri and others (2004). Moreover, the additional requirements of idiomatic processing can be expected to involve additional areas, in particular in the prefrontal cortex, as suggested by neuropsychological (Papagno and others 2006) and neurophysiological findings (Rizzo and others 2007). The involvement of the prefrontal cortex may be due to its role in high-level cognitive operations, such as cognitive control (Koechlin and others 2003), response monitoring (Ridderinkhof and others 2004) and coordination between multiple cognitive operations (Ramanani and Owen 2004).

Material and methods

Materials. Sixty-two idioms in Italian and sixty-two literal Italian sentences were selected for this study. All idioms were judged as highly familiar in a population of 101 subjects of different age (range 22-65), from different regions of Italy, thirty being ambiguous (the literal interpretation was also plausible, i.e. “to cut the rope” meaning “to escape”) and thirty-two not (the literal interpretation was not plausible, i.e. “to stay at the ribs” meaning “to follow someone at a very close distance”). However, we re-assessed familiarity in the participants’ group, after they had completed the fMRI session. The mean index of familiarity on a three-point scale was 2.68 (range 1.5-2.9, SD = 0.3). The degree of transparency was checked by asking thirty healthy subjects (mean age = 26, range 20-32) to rate how easily the meaning of the idiom could be deduced from the concrete image evoked by the sentence: a score

ranging from 0 to 5 was assigned, where 0 meant “not at all” and 5 “entirely”. This index varied between 1.9 (item 55) and 4.4 (item 16) (mean = 3.1, SD = 0.6)(see Appendix). Literal sentences were matched in length with idioms. For each sentence, be it literal or idiomatic, a line-drawing picture was created. Half of them correctly represented the meaning of the sentence, half did not. In the case of idioms the correct picture represented the figurative meaning, i.e. for the idiom “to have a green thumb”, the picture represented a woman well taking care of plants (Figure 1 A). The wrong picture represented the opposite of the figurative meaning, i.e. for the idiom “tirare la cinghia” (to pull one’s belt), meaning “to starve, being very poor” the picture represented a rich man eating voraciously in a restaurant (Figure 1 B). The thirty healthy subjects who rated transparency were also asked to rate how closely the picture corresponding to the idiomatic meaning represented the idiom or its opposite. A score ranging from 0 to 5 was assigned, where 0 meant “not at all” and 5 “perfectly”. The mean score for idiomatic relatedness was 3.6 (range 1.6-4.8, SD = 0.7). In the case of literal sentence the correct picture exactly matched the sentence (such as in Figure 1 C), while the wrong picture differed in one element, i.e. for the sentence “ the man opens the window” the wrong picture represented a man opening a door (see Figure 1 D). Idiomatic and literal sentences were matched for length and syntactic complexity (see Appendix)

Insert Figure 1 about here

Participants.

Twenty-two right-handed students from the University of Milano-Bicocca volunteered to take part in the experiment (13 women and 9 men; mean age

25, range 19-40). They all gave informed consent to participate in the study. They were all Italian native monolingual students. None of them had a history of neurological or psychiatric disorders. Handedness was assessed by using the Handedness Inventory Questionnaire (Oldfield 1971). The study was approved by the local Ethics Committee.

Procedure. The experiment was run in 4 blocks (corresponding to the 4 scanning sessions, see below). Each block consisted of 31 trials. In each trial subjects were presented with a written sentence, either literal or idiomatic, and a picture. First, the sentence was presented on the upper part of the screen. After 2000ms a picture appeared below the sentence. Both the sentence and the picture remained on the screen for additional 3400ms. Participants were instructed to judge whether the picture represented the meaning of the sentence or not, and responded by pressing one of two response keys with the right index finger (green button for matching and red button for non-matching sentence-picture pairs). Reaction times (RTs) and accuracy were taken as behavioural data. Stimuli were presented in a randomized order by means of Presentation 0.91 (Neurobehavioral Systems, Albany, CA, USA), and viewed via a back-projection screen located in front of the scanner and a mirror placed on the head coil. Behavioural responses were collected via a fiber-optic response box.

Functional MRI acquisition

MRI scans were acquired on a 3T Intera Philips body scanner (Philips Medical Systems, Best, NL) using an 8 channels SENSE head coil (sense reduction factor = 2). Whole-brain functional images were obtained with an echo-planar T2* sequence, using blood-oxygenation-level-dependent contrast. Each functional image comprised 30 contiguous axial slices (4 mm thick), acquired in

interleaved mode, with a repetition time of 2200 ms (echo time: 30 ms; field of view: 240 mm x 240 mm). Each participant underwent 4 functional scanning sessions of 136 brain volumes each. The time interval between functional scanning sessions was between 1 and 2 minutes, i.e. the time necessary to initialize a new scanning sequence.

Data analyses

Statistical parametric mapping (SPM2, Wellcome Department of Imaging Neuroscience, London, UK) was used for image realignment (Andersson and others 2001), normalization to the Montreal Neurologic Institute (MNI) standard space, smoothing by a 6 mm FWHM Gaussian kernel, and General Linear Model statistical analysis (Friston and others 2002). We adopted a two-stage random-effects approach to ensure generalizeability of the results at the population level (Penny and Holmes 2003).

First-level statistical models

At the first stage, the time series of each participant were high-pass filtered at 67s and pre-whitened by means of an autoregressive model AR(1) (Andersson and others 2001). No global scaling was applied. Hemodynamic evoked responses for all experimental conditions were modelled as a set of hemodynamic response function, including the canonical response function, its first derivative (modelling for temporal latency effects) and its second derivative (modelling for dispersion effects). The first-level individual design matrices included the data of all four scanning sessions. For each session, we modelled the four experimental conditions (idiomatic sentence, true response (IT); idiomatic sentence, false response (IF); literal sentence, true response (LT); literal sentence, false response (LF), with the onset of the hemodynamic response functions time-locked to the appearance of the sentence on the

screen. A set of Student's t-test contrasts were defined for use at the second statistical level: these consisted in one contrast per experimental condition (IT, IF, LT, LF) per hemodynamic response function (canonical, first derivative, second derivative).

Second-level statistical models

At the second stage of analysis, the effects obtained at the single-subject level were used to compute an ANOVA assessing their significance at the group-level ($n = 22$ participants). The ANOVA included the set of all first-level t-test contrasts of all participants. We used F-contrasts to assess the following effects of interest: a) Conjunction null (Nichols and others 2005) between all experimental conditions (IT, IF, LT, LF); b) Main effect of idiomatic vs. literal sentences ((IT + IF) vs. (LT + LF)); c) Direct comparisons (IT vs. IF; LT vs. LF; IT vs. LT; IF vs. LF). The direction (tail distribution) of the effects (idiomatic vs. literal) was assessed by inspecting the plots of the contrast estimates with 90% confidence intervals in SPM2. All reported effects relate to voxel-level statistics ($P < 0.05$ with family-wise error (FWE) type correction for multiple comparisons).

We assessed the cytoarchitectonic probability of activations in Broca's area, using the probability maps (Amunts and others 1999) for BA 44 and BA 45 available with the SPM Anatomy toolbox (http://www.fz-juelich.de/ime/spm_anatomy_toolbox).

Additional analyses: excluding for potential differences between ambiguous and non-ambiguous idiomatic sentences

Ambiguous idioms can be also assigned a literal interpretation in an appropriate context (e.g. kick the bucket). Given that aphasic patients produce different patterns of errors with ambiguous and non-ambiguous idioms, and double dissociations have been reported (Papagno & Caporali

2007), one could expect that different processes recruiting different cortical substrates are involved. In addition, in a recent fMRI study on idiom comprehension (Zemleni and others 2007) unambiguous sentences elicited significantly increased activation rather than the ambiguous sentence. To exclude that ambiguous and non-ambiguous idiomatic sentences recruited different brain regions or the same brain regions to a different extent, we performed a control statistical analysis, in which the two types of idiomatic sentences were modelled separately. To this aim, we specified an additional first-level statistical model for each participant. The same parameters as in the statistical analysis described above were used. However, in this control statistical analysis, we modeled, instead of four, six experimental conditions [ambiguous, idiomatic sentence, true response (AIT); ambiguous, idiomatic sentence, false response (AIF); non-ambiguous, idiomatic sentence, true response (NIT); non-ambiguous, idiomatic sentence, false response (NIF); literal sentence, true response (LT); literal sentence, false response (LF)]. In addition, to correct for the potential bias produced by the different number of stimuli across conditions, this model also included a parametric modulation, consisting in a convolution with a constant value for each condition equal to the number of stimuli in that particular condition (AIT : 22; AIF: 8; NIT: 9; NIF: 23; LT: 31; LF: 31). In contrast with the previous analysis, the 4 functional scanning sessions were modeled as one single session. This choice was necessary in order to circumvent the fact that for some experimental conditions there was a very small number of stimuli in some of the functional scanning sessions. Nevertheless, to account for the 4 separate functional scanning sessions, we added 4 constant regressors: each regressor included values of 1 for the scans of one particular session and values of 0 for the scans of the other 3 sessions.

At the second statistical level, we used F-contrasts to assess the following effects of interest: a) Main effect of idiomatic vs. literal sentences [(AIT + AIF + NIT + NIF) vs. (LT + LF)]; b) Effect of ambiguous vs. non-ambiguous idiomatic sentences [(AIT + AIF) - (NIT + NIF)]. The main effect of idiomatic vs. literal sentences (contrast a) was only included in order to check for the consistency between this control analysis and the main analysis described in the paper: importantly, there were

no relevant qualitative differences between the two analyses for this particular contrast.

Dynamic Causal Modelling (DCM)

A complementary approach to the investigation of brain functional specialisation related to the individual task is the analysis of functional integration, by means of methods which estimate the coupling of brain areas and the influence of experimental manipulations on that coupling (Lee and others 2006). One of these methods is Dynamic Causal Modelling (DCM), which derives connectivity parameters for the influence of the experimental conditions on brain states, for the intrinsic connections between the brain areas included in the system, and for the changes in connectivity between areas induced by the experimental conditions (bilinear terms) (Friston and others 2003). Concretely, we used DCM to measure how the significant main effect 'IDIOMATIC > LITERAL' is conveyed from the input area, via the specified connections, to other areas. To this purpose, a set of five anatomical regions of interest was selected based on the result of the main effect 'IDIOMATIC > LITERAL' (i.e. the anterior medial frontal gyrus (input area), the left and right inferior frontal gyrus and the left and right anterior middle temporal gyrus). We then defined a set of connections between the five regions of interest to test whether the activity of the anterior medial frontal gyrus had an influence on the activity in perisylvian areas.

As for the General Linear Model analysis, also for the DCM analysis we adopted a two-stage random-effects approach. At the single-subject level, we implemented a dynamic causal model including the following five brain regions: the anterior medial frontal gyrus ($x = -4$, $y = 54$, $z = 32$), the left inferior frontal gyrus ($x = -50$, $y = 26$, $z = 0$), the left anterior middle temporal gyrus ($x = -58$, $y = -6$, $z = -20$), the right inferior frontal gyrus ($x = 52$, $y = 32$, $z = -8$), and the right anterior middle temporal gyrus ($x = 58$, $y = -8$, $z = -20$).

Spherical volume of interests of 6-mm radius centred on these coordinates were extracted for all participants, using the F-contrast over all the effects of

interest. A separate input for all four experimental conditions was allowed to enter the dynamic causal model at the medial prefrontal area. The resulting perturbation was then allowed to propagate throughout the network via interconnections between the medial prefrontal area and the remaining regions (see Figure 2). In such a model, in which separate inputs for all experimental conditions are provided, the DCM analysis measures how the significant main effect (in this case 'IDIOMATIC > LITERAL') that is induced in the input area is conveyed, via the specified connections, to other areas (effective connectivity). In this case, the focus is on the intrinsic connections, and not on the bilinear terms. Therefore, we only report the data concerning the intrinsic connections, measuring the effective connectivity of one region over another. The ensuing subject-specific parameters of the intrinsic connections were then taken to a second level for population inference (Penny and Holmes 2003). One-sample t tests on the intrinsic connections were performed. As this was repeated for several connections, we adopted a conservative statistical threshold of $p < .001$.

Insert Figure 2 about here

Results

Behavioural data

The literal and nonliteral sentences were matched for length and syntactic complexity. However, subjects' mean RTs significantly differed between conditions [$F(1, 21) = 674.43, p < .0001$], the subjects being faster with literal ($M = 1373.4, SD = 224.1$) than idiomatic sentences ($M = 1563.3, SD = 299.4$), while there was no difference between true/false responses [$F(1, 21) = 23.92, p = .72$]. Indeed, the mean RT for true responses was 1550.9 for idioms and 1364 for literal sentences, while for false responses it was 1551 for idioms and 1386 for literal sentences. The interaction was not significant [$F(1, 21) = 0.22, p = .65$].

Accuracy was very high in both conditions ($M = 56.1, SD = 4.6$ out of a total of 62 idioms, and $M = 58.9, SD = 2.1$ out of a total of 62 literal sentences) despite a lower accuracy for nonliteral sentences with respect to literal sentences, which was significant [$F(1, 21) = 11.35, p < .005$], while there was no difference between true and false sentences [$F(1, 21) = 0.77, p = .39$], nor the interaction true/false x literal/nonliteral was significant [$F(1, 21) = 0.39, p = .85$].

We also compared RTs and accuracy for ambiguous and non-ambiguous idioms, and no significant difference was found ($p = .06$ and $p = .2$, for accuracy and RTs respectively). Finally, accuracy did not prove to correlate with familiarity ($r = -.11$), nor with transparency ($r = .33, p = .13$).

Imaging data

1) *Conjunction Null*. A network of bilateral brain activation covering frontal, parietal, temporal and occipital areas was found. More specifically, in the left hemisphere this network involved the inferior frontal gyrus (LIFG; BA44/45), the precentral gyrus (BA6), the postcentral gyrus, the inferior parietal lobule

(BA40), the insula, the middle temporal gyrus, the rolandic operculum and the fusiform gyrus. The experimental task also engaged a pattern of visual areas including the left middle and left inferior occipital gyri (BA19 and BA18). Subcortical bilateral activation was found in the left thalamus and left cerebellum (see Table1).

In the right hemisphere, activations were found in the inferior and superior frontal gyri, the insula, the middle cingulate cortex, superior and middle temporal gyri, and fusiform gyrus, as well as in the canonical areas engaged by visual tasks, such as the superior, middle and inferior occipital gyri. Subcortical activation involved the caudate nucleus and thalamus. Activation was also found in the cerebellum. Bilateral clusters of activation were found medially in the frontal gyrus, supplementary motor area, and anterior cingulum.

2) *Idiomatic versus Literal sentences*. A bilateral fronto-temporal network of increased cortical activity was found for idiomatic compared to literal sentences. The idiomatic condition activated bilaterally the inferior frontal gyrus and the anterior middle temporal gyrus (BA21), while in the left hemisphere activation of the superior frontal gyrus in its anterior, medial part, of the inferior temporal gyrus and of the angular gyrus (BA39) was observed. Finally, in the right hemisphere activation was seen in the middle temporal gyrus and in the temporal pole.

Literal versus idiomatic sentences activated the supramarginal gyrus (BA40) bilaterally and the superior (BA7) and inferior (BA40) parietal lobules in the right hemisphere. (see Table 2 and Figure 3)

Insert Figure 3 about here

3) *Direct comparison between the four conditions.* No suprathreshold clusters of activation were found, suggesting that within idiomatic and literal condition, the pattern of activation was unaffected by true/false condition.

4) *Control analysis: ambiguous vs. non-ambiguous idiomatic sentences.* No significant differences were found between ambiguous and non-ambiguous idiomatic sentences, even at an uncorrected significance threshold of $P < 0.001$. This indicates that the results reported above were not biased by having ambiguous and non-ambiguous idiomatic sentences conflated within the idiomatic experimental conditions.

5) *DCM analysis.* The results are shown in Table 3. One sample t-test analyses showed that, at the group-level, all the intrinsic connections included in our model were significantly different from zero for the main effect of Idiomatic minus Literal sentences. In other words, the Idiomatic-specific activation of the medial prefrontal area elicited a significantly greater effective connectivity between the brain regions included in the dynamic causal model for Idiomatic vs. Literal sentences.

Discussion

In the current study, fMRI was used to examine the brain areas involved in the processing of idiomatic sentences. We used a judgment task, in which the

participants had to decide whether or not the meaning of a sentence matched a picture. The results reveal that making yes/no judgments about literal and nonliteral sentences yielded a similar network of activity, involving the language areas of the LH. However, accessing the nonliteral meaning led to overall higher levels of activation. We found an activation of the left temporal cortex, as predicted by neuropsychological and rTMS studies. In addition, in line with previous studies using different methodologies, the left superior frontal (approximately covering BA 9), as well as the left inferior frontal gyrus (IFG), were specifically involved in processing idiomatic sentences. Activations were also seen in the right superior and middle temporal gyrus, in the temporal pole, and in the right IFG. In contrast, literal sentences activated the left inferior parietal lobule and the right supramarginal gyrus.

The findings of the present study, therefore, are in line with recent fMRI studies performed with metaphors, using different paradigms, such as reading and judging metaphor plausibility (Rapp and others 2004) or choosing the two adjectives, out of three, which had the same metaphorical meaning (Lee and Dapretto 2006). A bihemispheric network, involving the inferior frontal gyrus bilaterally and the left middle temporal gyrus has been also recently reported (Zemleni and others 2007).

The activation of the left inferior parietal lobule with literal sentences may be related to differential requirements of phonological memory resources in order to assess the matching between the sentence and the picture. Since in the case of idiomatic sentences a picture can only depict a concrete instantiation of the figurative meaning that is generally abstract, the participant needs to decide whether this is appropriate or not. This decision requires a central executive involvement to maintain the sentence and then

match it to the picture. In contrast, the detection of a possible mismatch for the literal sentence may require only a verbatim retention of the sentence, for which the phonological loop is necessary. Overall, subjects took longer and were less accurate in the idiomatic condition, suggesting that the greater activity and the prefrontal involvement could in part reflect the additional task demands of holding in memory different interpretations and matching them with the picture, while switching from one meaning to the other. This activation result parallels the one obtained on metaphor comprehension (Lee and Dapretto 2006). A number of investigations have linked activity in the left IFG to the selection of semantic knowledge among competing alternatives or, more in general, to the selection among alternatives without necessarily involving semantics (Zhang and others 2004). Accordingly, this region was strongly activated in the present study during the idiomatic condition, in which two different meanings (the literal and the idiomatic) were presumably retrieved and evaluated in order to accomplish the task.

Furthermore, no difference was found between ambiguous and non-ambiguous idioms, suggesting that, at least at a gross level, processes and neural correlates are the same for both types of idiomatic sentences. However, this is in contrast with recent neuropsychological data on aphasic patients and with the fMRI study by Zempleni and others (2007), in which an additional right temporal activation was found in the case of ambiguous items and deserves further investigation.

An additional finding in our study was the involvement of the anterior-medial part of the superior frontal gyrus, with a left-sided preponderance. The anterior prefrontal cortex has been recently considered to be specifically involved in integrating the outcomes of two or more separate cognitive

operations in the pursuit of a higher behavioural goal. Christoff and Gabrieli (2000) suggested that the anterior prefrontal cortex might be specialized for the explicit processing of internal mental states and events. In particular, tasks that require the generation and monitoring of internally generated responses should activate this region, an example being the Tower of London Test, in which possible solutions must be internally generated and then accepted or rejected, before making a move (Wagner and others 2006). Alternatively, Ramnani and Owen (2004) proposed that the anterior prefrontal cortex is engaged when problems involve more than one cognitive process: that is when the application of one cognitive operation (such as a rule) on its own is not sufficient to solve the problem as a whole, and the integration of the results of two or more separate cognitive operations is required to fulfill the higher behavioural goal. Multiple, related cognitive operations can only be successfully performed if they are coordinated. One can speculate that the coordination of information processing and information transfer between multiple operations across supramodal cortex is an important aspect of anterior prefrontal cortex function. Applying this theory to idiom comprehension, it can be argued that the sentence is linguistically analysed, producing two possible interpretations: the literal and the figurative. Both are matched with the context and eventually one or the other is accepted (or, in some other cases, both may be rejected). In the present experiment, the coordination of the different interpretations with the meaning of the picture is required only in the case of idiom comprehension. In the case of literal sentence, the meaning of the picture needs to be matched with one interpretation only.

An additional support to this view comes from the results of the dynamic causal model (DCM) analysis. In defining our model, we hypothesized that the

specific effect of sentence type leading to an activation of the anterior medial frontal gyrus would propagate to perisylvian regions, bilaterally, in terms of an increased effective connectivity for idiomatic vs. literal sentences. Our results do indeed favour this view. This may suggest that the anterior medial frontal gyrus has a prominent role in regulating the cross-talk between perisylvian language areas, and that the coherence of activation in these areas is higher when a choice between two competing hypotheses is required, such as in the case of idiomatic sentences. The anterior medial frontal gyrus might mediate the inhibition of the alternative interpretation in favour of the correct one. In this context, the salience of the anterior medial frontal gyrus as an input region, as opposed to other brain regions, was also confirmed by comparing the DCM described here with a second model that included the same brain areas, but in which the psychological input was delivered to the middle temporal gyrus, bilaterally, rather than to the medial frontal gyrus (details not shown). In all the 22 subjects, the model with input to the medial frontal gyrus leads to a better fit than the model with input to the middle temporal gyri.

The present data undermine the hypothesis of a specific role of the RH, also in this type of figurative language, as it has been already demonstrated in the case of metaphors (Lee and Dapretto 2006). Overall, they support the view that idiomatic language follows the same procedure as literal language, plus a selection process between alternative meanings, which is likely to be supported by the IFG, and a supplementary high level cognitive process, supported by the anterior prefrontal cortex, possibly monitoring and integrating the results of the linguistic analysis and of the selection between competing meanings.

Therefore, the results of the present study provide strong evidence against

the Lexical Hypothesis (Swinney and Cutler 1979), since it is unlikely that such a complex network would be activated in the case that idioms were treated as single complex words. Instead, they are consistent with the *Configurational Hypothesis* suggested by Cacciari and Tabossi (1988), which proposes that the individual components of the idiom are analyzed as normal linguistic items, until a key part is processed that prompts the recognition of the idiomatic nature of the string, and the activation of its figurative meaning. In functional terms, the linguistic analysis engages an extensive bihemispheric network, with left-sided prevalence. The additional processing required by idiomatic sentences is reflected by the recruitment of other frontotemporal regions in the two hemispheres, with a key role of the left anterior and anteromedial prefrontal cortex. The necessary role of the LH within the network is supported by TMS data (Rizzo and others 2007), showing that rTMS applied over the left BA 9 reduces accuracy in the case of idiomatic but not literal sentences. This is particularly evident when rTMS is applied 80 ms after picture presentation.

Additional converging evidence is provided by the results of neuropsychological studies (Papagno and others 2006). An impaired performance has been found in both LBD and RBD patients, whose lesions were mapped following Damasio and Damasio's procedure (1989). However, while all LBD patients were significantly impaired, no matter if the lesion was frontal or temporal (although the most severely impaired patients exhibited an overlapping damaged area in the temporal lobe), in the case of RBD, only those with a right prefrontal lesion were found impaired, suggesting that this region could be involved in inhibiting the literal interpretation or, alternatively, in retrieving/activating the figurative one. The absence of a right prefrontal lesion effect on literal sentence comprehension is in line with the present experiment,

showing that this area is selectively involved in idiom comprehension and not in any task requiring a selective choice. It is worth mentioning that in neuropsychological studies a sentence-to-picture matching task is used, the foils often including the literal representation of the sentence, which could force a literal interpretation. The absence of literal alternatives in the present experiment should have minimised this effect.

Finally, the *Graded Salience Hypothesis* (Giora 1997) suggests that accessing the meaning of salient nonliteral meanings, such as the ones used in the present study, would not be contingent upon the availability of contextual information and, as such, retrieval of these meanings need not require RH involvement, relying instead on LH mechanisms. However, we found an activation of the RH even with conventional, familiar idioms. A possible explanation is suggested by Kacirik and Chiarello (2006), who argued that RH can maintain various possible interpretations and this sustained activation of inconsistent meanings may act as a backup system in the event that the interpretation of an expression needs to be revised. Moreover, several neuroimaging studies indicate that the RH is recruited whenever contextual and semantic information needs to be integrated in order to interpret ambiguous language (e.g. Beeman and Chiarello 1998; Rodd and others 2005).

In conclusion, converging evidence (neuropsychological studies, neurophysiological studies using rTMS, and fMRI studies) suggests that the prefrontal cortex is involved in idiom interpretation. Further studies avoiding the use of pictorial material need, however, to be run in order to confirm this result. In addition, a higher number of literal sentences as compared to idiomatic need to be included in the experimental set to avoid specific strategies. Finally, a comparison between different types of idioms (ambiguous

vs non-ambiguous, opaque vs transparent and so on) is the next step required to check if the intrinsic linguistic properties of idioms result in a different pattern of brain activity.

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Table 1. Conjunction among the four experimental conditions.

Stereotactic Coordinates (x, y, z) for Significant Clusters (Random Effects, FWE $p < 10^{-6}$ corrected) are given in millimetres together with Effect Sizes ($Z = Z$ score). We also report the cytoarchitectonic probability (CP%) of activations in Broca's area, using the probability maps (Amunts and others, 1999) for BA 44 and BA 45 available with the SPM Anatomy toolbox. Inf = Infinite.

<i>Area</i>	<i>Zscore</i>	<i>x,y,z</i>	<i>CP%</i>
L Inferior Frontal Gyrus	Inf	-46, 28, 16	BA45 (30%)
L Inferior Frontal Gyrus	Inf	-52, 16, 28	BA44 (40%)
L Precentral Gyrus	Inf	-44, -12, 60	
L Precentral Gyrus	Inf	-56, 2, 32	
L Insula	Inf	-32, 20, 0	
L Postcentral Gyrus	Inf	-34, -30, 52	
L Inferior Parietal Lobule	Inf	-44, -42, 48	
L Rolandic Operculum	7.58	-48, -24, 16	
L Middle Temporal Gyrus	7.16	-34, -52, 0	
L Fusiform Gyrus	Inf	-38, -52, -24	
L Middle Occipital Gyrus	Inf	-34, -84, 16	
L Inferior Occipital Gyrus	Inf	-46, -78, -4	
L Thalamus	Inf	-14, -22, 8	
L Cerebellum	Inf	-32, -68, -20	
R/L Medial Frontal Gyrus	Inf	-4, 56, 4	
R/L Supplementary Motor Area	Inf	-2, -2, 56	
R/L Anterior Cingulate Gyrus	Inf	-2, 42, -4	
R Superior Frontal Gyrus	7.21	38, -6, 64	
R Inferior Frontal Gyrus	Inf	50, 28, 16	BA45 (70%)
R Inferior Frontal Gyrus	Inf	50, 8, 28	BA44 (40%)
R Insula	Inf	32, 22, -4	
R Middle Cingulate Cortex	7.27	10, -50, 32	
R Superior Temporal Gyrus	7.32	62, -4, 0	
R Middle Temporal Gyrus	Inf	54, -68, 0	
R Fusiform Gyrus	Inf	44, -52, -20	
R Superior Occipital Gyrus	Inf	22, -76, 36	
R Middle Occipital Gyrus	Inf	44, -70, 8	
R Inferior Occipital Gyrus	Inf	46, -76, -12	

R Caudate Nucleus	Inf	10, 8, 8
R Thalamus	Inf	12, -16, 4
R Cerebellum	Inf	34, -46, -28

Table 2. Direct comparison: Idiomatic vs Literal sentences

FWE ($p < .05$) corrected

<i>Area</i>	<i>Zscore</i>	<i>x,y,z</i>	<i>CP%</i>
IDIOMATIC > LITERAL			
L Medial Frontal Gyrus	Inf	-4, 54, 32	
L Superior Frontal Gyrus	6.79	-10, 48, 48	
L Inferior Frontal Gyrus	Inf	-50, 26, 0	BA45 (30%)
L Angular Gyrus	6.16	-50, -58, 24	
L Anterior Middle Temporal Gyrus	7.42	-52, 4, -32	
L Inferior Temporal Gyrus	Inf	-52, 6, -40	
R Inferior Frontal Gyrus	6.02	52, 32, -8	BA45 (20%)
R Middle Temporal Pole	6.87	46, 12, -36	
R Anterior Middle Temporal Gyrus	6.15	54, 0, -24	
R Posterior Middle Temporal Gyrus	5.61	52, -48, 12	
LITERAL > IDIOMATIC			
L Supramarginal Gyrus	5.56	-58, -32, 40	
R Superior Parietal Lobule	5.18	42, -46, 60	
R Inferior Parietal Lobule	5.45	58, -36, 52	
R Supramarginal Gyrus	5.51	62, -28, 36	

Table3. DCM: Estimated Parameters for the Intrinsic Connections, which refer to the coupling between two regions (effective connectivity over intrinsic connections, $p < .001$). Mean parameters (mean), standard deviations (SD) and two-tailed statistical significance (p) are reported. (See Fig X for a description of the areas and of the intrinsic connections of the model)

<i>Intrinsic Connections</i>	<i>Mean</i>	<i>SD</i>	<i>p</i>
mFG → LIFG	0,086	0,143	< .0001
mFG → LMTG	0,074	0,128	< .0001
mFG → RIFG	0,068	0,132	< .0001
mFG → RMTG	0,054	0,105	< .0001
LIFG → LMTG	0,011	0,029	< .001
LMTG → LIFG	0,014	0,033	< .001
RIFG → RMTG	0,005	0,013	< .001
RMTG → RIFG	0,009	0,024	< .001

Captions to figures

Figure 1. Examples of the pictures used in the experimental task.

A is a correct picture for the idiom “avere il pollice verde”(to have a green thumb). B is a wrong picture representing the opposite of the idiomatic meaning of “tirare la cinghia” (to pull one’s belt, meaning “to starve, being very poor”). C is a correct picture for the literal sentence “the boy is eating an apple”. D is a wrong picture for the literal sentence “ the man is opening the window”.

Figure 2. Dinamic Causal Model.

Dynamic causal model used to test the hypothesis of a driving role of the anterior prefrontal area in inhibiting the alternative interpretation in the case of idiomatic sentences, by coordinating the activity in perisylvian areas. The model includes 5 brain regions: the left anterior middle temporal gyrus (LMTG), the right anterior middle temporal gyrus (RMTG), the left inferior frontal gyrus (LIFG), the right inferior frontal gyrus (RIFG), and the anterior medial frontal gyrus (mFG). The MNI coordinates are displayed on the right. The black arrows indicates forward/backward intrinsic connections between two anatomical nodes.

Figure 3. Idiomatic vs literal sentences.

A) Activations for the two experimental conditions (white, idiomatic > literal; black, literal > idiomatic) are superimposed on the lateral surfaces of a cortical rendering, representing the mean anatomical T1 image of the 22 participants. Contrasts of parameter estimates, with 90% confidence intervals, for two representative activations are shown below: B) Idiomatic > literal: left inferior

frontal gyrus ($x = -50$, $y = 26$, $z = 0$); C) Literal > idiomatic: left supramarginal gyrus ($x = -58$, $y = -32$, $z = 40$). In these two regions, and in all the other significantly activated regions, a common activation pattern was found, with the amplitude of the canonical hemodynamic response function being significantly larger for one of the two conditions, and the effects for the first and second derivatives having the reverse sign. A larger effect for the first and second derivative means that the temporal and the dispersion profile of the hemodynamic response, respectively, presented a higher variance. In other words, the activations with a higher amplitude for e.g. the idiomatic sentences, also presented a consistently more uniform temporal profile and consistently less dispersion for idiomatic vs. literal sentences.

Figure 1

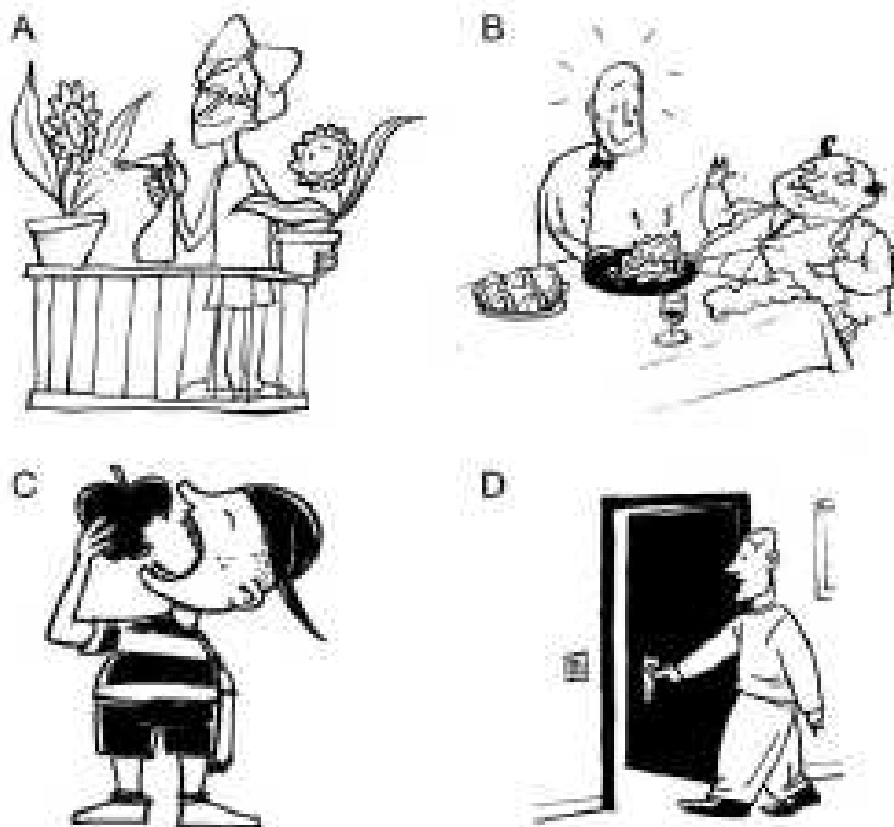
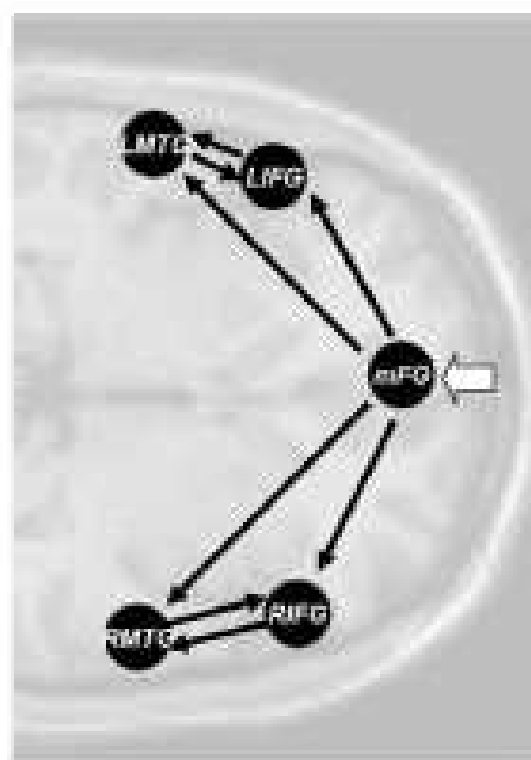


Figure 2



Location of regions

Name	MNI Coordinates
LMTG	-52 -8 -20
RMTG	62 -12 -20
LFG	-54 22 0
RIFG	56 28 -4
mFG	-4 54 32

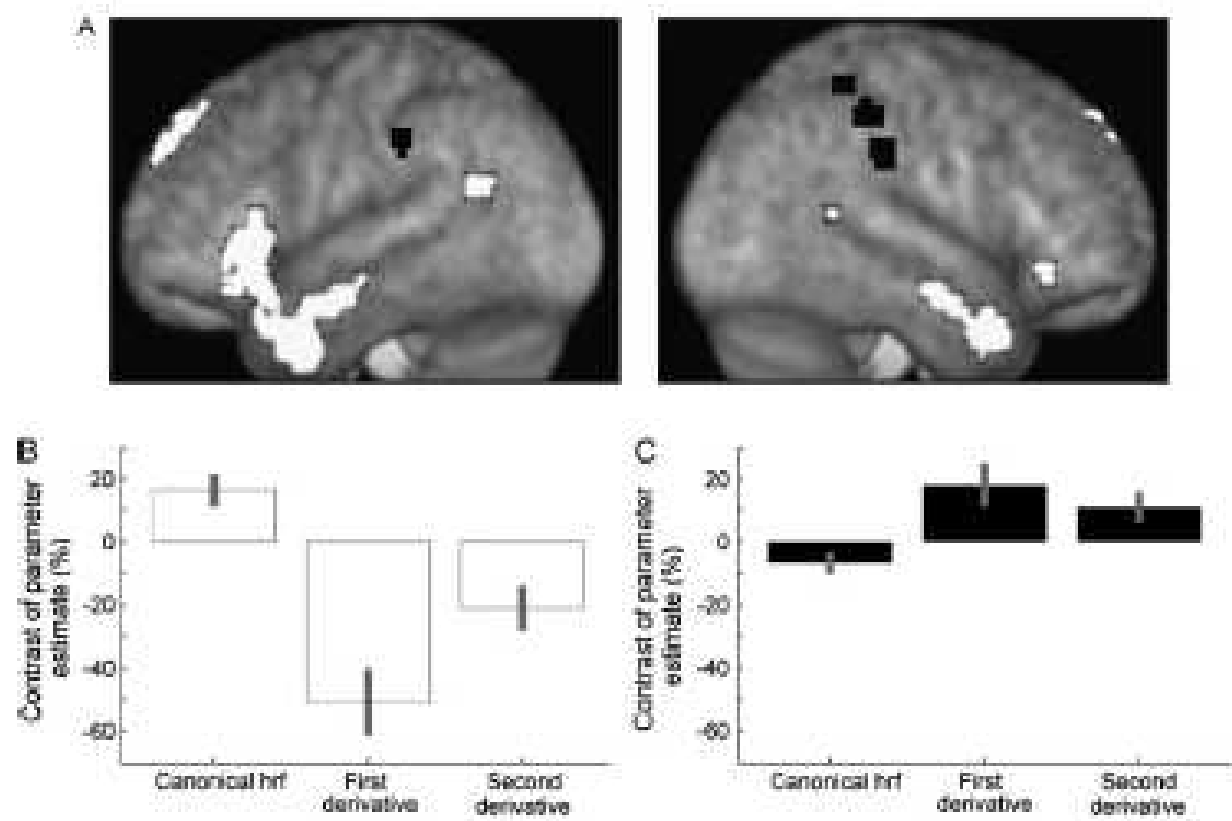


INPUT



INTRINSIC CONNECTIONS

Figure 3



Appendix	Familiarity index (0-3)	Transparency (0-5)	Picture Relatedness (0-5)
Andare al fresco	2.7	2.5	3.8
Andare in bestia	2.9	3.8	4.0
Avere i minuti contati	2.9	4.0	3.4
Avere il cuore in mano	2.2	2.9	3.0
Avere il pollice verde	2.9	3.0	4.5
Avere le mani in pasta	2.5	2.8	3.6
Avere la puzza sotto il naso	2.9	3.0	3.9
Avere poco sale in zucca	2.7	2.7	3.2
Dare del filo da torcere	2.9	2.9	4.4
Dare i numeri	2.9	2.4	1.6
Essere a piede libero	2.4	3.4	4.5
Essere al settimo cielo	2.9	3.7	4.2
Essere di facili costumi	2.9	3.1	4.1
Essere in forma	2.9	4.1	3.5
Essere sul viale del tramonto	2.3	3.4	3.1
Essere sulla cattiva strada	2.8	4.4	4.0
Essere uno stinco di santo	2.7	3.0	4.5
Far venire il latte alle ginocchia	2.6	2.3	3.1
Fare fiasco	2.7	2.4	4.2
Farsene un baffo	2.6	2.1	3.5
Mandare a monte	2.9	2.0	3.6
Mettersi le gambe in spalla	2.1	2.5	3.0
Montarsi la testa	2.9	3.1	2.1
Mordere il freno	1.5	2.3	2.0
Non vedere l'ora	2.9	3.3	2.4
Perdere la faccia	2.7	3.1	2.1
Prendere fischi per fiaschi	2.6	3.3	3.4
Prendere in castagna	2.7	2.6	4.7
Restare con un palmo di naso	2.6	2.3	4.2
Rimetterci le penne	2.8	3.6	4.8
Spremere le meningi	2.8	3.9	2.0
Stare alle costole	2.6	3.3	2.6
Stare in campana	2.3	2.3	2.7
Tendere le orecchie	2.5	3.9	4.1
Tenere banco	2.4	2.8	2.4
Vendere cara la pelle	2.3	3.6	4.1
Venire alle mani	2.7	3.6	4.0
Alzare i tacchi	2.7	3.4	3.4
Alzare il gomito	2.8	3.0	2.3
Attaccare bottone	2.9	2.7	4.2
Avere le mani bucate	2.8	3.2	3.7
Chiudere un occhio	2.9	3.7	3.8
Essere al verde	2.9	2.6	3.9
Gettare la spugna	2.9	2.9	4.4
Levare le tende	2.5	3.8	4.0
Mangiarsi il fegato	2.7	2.7	4.0
Mettere la pulce nell'orecchio	2.8	3.0	3.9
Mettersi le mani nei capelli	2.8	3.6	3.5
Perdere il filo	2.8	2.9	4.0
Perdere la bussola	2.5	3.8	3.8
Perdere la testa	2.9	3.9	2.2
Prendere la porta	2.3	3.1	3.9
Prendere un granchio	2.6	2.6	4.4

Rompere il ghiaccio	2.9	2.7	3.7
Saltare la mosca al naso	2.0	1.9	2.4
Scendere a rotta di collo	2.2	3.0	4.1
Sputare il rospo	2.9	2.8	3.4
Stringere i denti	2.9	3.6	3.7
Tagliare la corda	2.8	2.9	4.8
Tirare la cinghia	2.8	3.0	3.8
Vedere le stelle	2.8	2.9	4.4
Vuotare il sacco	2.8	3.5	4.0

