

An fMRI investigation of the neural correlates underlying the processing of novel metaphoric expressions

N. Mashal^{a,d,*}, M. Faust^{a,b}, T. Hendler^{c,d}, M. Jung-Beeman^e

^a *The Leslie and Susan Gonda (Goldschmied) Multidisciplinary Brain Research Center, Bar-Ilan University, Israel*

^b *Department of Psychology, Bar-Ilan University, Israel*

^c *Sackler Faculty of Medicine, Tel Aviv University, Israel*

^d *Functional Brain Imaging Unit, Wohl Institute for Advanced Imaging, Tel Aviv Sourasky Medical Center, Israel*

^e *Department of Psychology and Cognitive Brain Mapping Group, Northwestern University, Evanston, IL, USA*

Accepted 1 October 2005

Available online 14 November 2005

Abstract

The neural networks associated with processing related pairs of words forming literal, novel, and conventional metaphorical expressions and unrelated pairs of words were studied in a group of 15 normal adults using fMRI. Subjects read the four types of linguistic expressions and decided which relation exists between the two words (metaphoric, literal, or unrelated). According to the Graded Salience Hypothesis (GSH, Giora, 1997, 2002, 2003), which predicts a selective RH involvement in the processing of novel, nonsalient meanings, it is primarily the degree of meaning salience of a linguistic expression rather than literality or nonliteral, which modulates the degree of left hemisphere (LH) and right hemisphere (RH) processing of metaphors. In the present study, novel metaphorical expressions represented the nonsalient interpretations, whereas conventional metaphors and literal expressions represented the salient interpretations. A direct comparison of the novel metaphors vs. the conventional metaphors revealed significantly stronger activity in right posterior superior temporal sulcus, right inferior frontal gyrus, and left middle frontal gyrus. These results support the GSH and suggest a special role for the RH in processing novel metaphors. Furthermore, the right PSTS may be selectively involved in verbal creativity.

© 2005 Elsevier Inc. All rights reserved.

Keywords: Novel metaphors; Salient; Right hemisphere; fMRI; Verbal creativity; PSTS

1. Introduction

Basic language functions such as production and processing are associated with the left hemisphere (LH). However, recent research suggests that the right hemisphere (RH) may also play a large and significant role in language processing. Studies with neurologically intact participants suggest that the RH contributes to the processing of some specific forms of language such as jokes (Coulson & Wu, 2005; Coulson & Williams, 2005; McDonald, 1996), metaphors (Anaki, Faust, & Kravetz, 1998; Bottini et al., 1994; Brownell, Simpson, Bihrl,

Potter, & Gardner, 1990; Mashal, Faust, & Hendler, 2005; Pynte, Besson, Robishon, & Poli, 1996), indirect requests (Weylman, Brownell, Roman, & Gardner, 1989), lexical ambiguity (Faust & Chiarello, 1998; Faust & Gernsbacher, 1996), and irony (Eviatar & Just, submitted). The aim of the present study was to use brain imaging to study brain correlates of metaphor processing and specifically the role of the RH in processing the nonsalient meanings of novel metaphors, which in turn might have some implications for RH involvement in verbal creativity.

Although, studies with neurologically intact participants seem to support a unique role for the RH in processing figurative language, research on the processing of metaphoric language in patients with left (LHD) and right (RHD) hemisphere damage has yielded conflicting results. In two studies with LHD and RHD patients

* Corresponding author. Fax: +972 3 5352184.

E-mail address: m_nira@012.net.il (N. Mashal).

(Rinaldi, Marangolo, & Baldassari, 2004; Winner & Gardner, 1977), findings suggested some dissociation between visuo-verbal and verbal tests of metaphor processing. Thus, in both studies subjects listened to sentences containing metaphoric expressions (i.e., *a heavy heart can really make a difference*) and were presented with four pictures that were related either to the metaphoric or the literal meaning of the sentences, or to a single word in the sentence. In the visuo-verbal task, the patients were asked to point to the picture that best represented the meaning of the sentence. RHD patients preferred the pictures related to the literal meaning of the sentence to those related to the metaphoric interpretation. However, they were able to explain verbally the metaphoric meaning of the sentences (Rinaldi et al., 2004; Winner & Gardner, 1977).

Findings of other studies (Giora, Zaidel, Soroker, Batori, & Kasher, 2000; Zaidel, Kasher, Soroker, & Batori, 2002) failed to support the claim that RH has a unique role in metaphor processing. In one of these studies (Giora et al., 2000), a large sample of RHD and LHD patients were presented with conventional metaphors (e.g., *“broken heart”*) with no plausible literal meaning, and were asked to provide oral verbal explanations. RHD patients did not show a selective bias toward the literal interpretation.

A recent ERP study (Sotillo et al., 2005) also suggests that the RH contributes to metaphor processing. In this study, neurologically intact participants read novel, poetry-styled, metaphoric sentences (*“Furious ground hump”*) followed by a word that could (*“volcano”*) or could not (*“camel”*) be associated with the metaphorical meaning of the sentence. The amplitude of the N400 component of the ERP, originating from the right superior/middle temporal gyrus, but not from the left, was larger for the metaphorically related words than for the non-related words. The N400 component reflects semantic processing of literal linguistic stimuli (Kutas & Besson, 1999) and, specifically, semantic expectancy, so that semantically anomalous endings to a sentence result in larger N400 amplitudes (Tartter, Gomes, Dubrovsky, Molholm, & Stewart, 2002). According to Sotillo et al. (2005), the N400 component in their paradigm cannot be explained by lack of predictability since the non-related words were less expected (more anomalous) than the related words. Although, the authors claimed that the non-related words (i.e., *“wolf”*) “had no relationship at all” with the sentence (i.e., *“Furious tube, that whistles and howls”*) it seems that they were lexically associated with the sentences (*wolf-howl*). Perhaps their results emphasize the distinction between literally and metaphorically related words showing that the metaphorically related words (and not the literally related words) increased activity in the right but not the left temporal gyrus.

Evidence from functional brain imaging studies of metaphor processing is also inconsistent. In the first study on metaphor processing using PET, subjects performed an explicit semantic judgment on metaphoric (*“Their cross mother was an elastic band”*) as compared to literal sen-

tences (*“The busy secretary used string as a bookmark”*) (Bottini et al., 1994). When compared to the literal sentences, processing metaphoric sentences elicited greater activation in right prefrontal regions, in the RH homologue of Wernicke’s area and RH temporal lobe, in addition to activation in several left hemisphere regions. In contrast, in another imaging study subjects read literal (*the lovers words are lies*) and metaphoric sentences (*lovers words are harp sounds*) and were asked to judge whether the sentences had positive or negative connotations (Rapp, Leube, Erb, Grodd, & Kircher, 2004). Metaphoric sentences elicited greater activation than did literal sentences in left lateralized brain regions: inferior frontal gyrus (BA 45/47), left inferior temporal gyrus (BA19/20), and left posterior middle temporal gyrus (BA37). However, it should be noted that, although the authors claimed that their stimuli were newly created, novelty or familiarity were not rated by judges. The possibility that the metaphoric sentences seemed familiar to subjects might explain the left lateralized activations. The authors suggested that semantic complexity, which characterized Bottini et al. (1994) stimuli, might determine the extent of RH involvement in metaphor processing, rather than the novelty of sentences (which characterized stimuli in both studies). It should be noted, however, that the use of a metalinguistic task in Bottini’s study, which requires some rather complex judgment processes that are not utilized during online language processing, could explain the RH involvement.

In another recent fMRI study (Stringaris, Medford, Giampetro, Brammer, & David, in press) participants read metaphoric (*“some surgeons are butchers”*), literal (*“some surgeons are fathers”*), or nonsense (*“some surgeons are shelves”*) sentences and decided whether the sentences made sense or not. Metaphoric sentences elicited greater activation than did literal sentences in left lateralized cortical brain regions including left IFG BA 47 (as in Rapp et al.’s study), left precentral gyrus (BA6), and left inferior parietal lobe (BA 40/19), as well as in right middle temporal gyrus (BA 39/19).

Although, as described above, the findings regarding the role of the RH in metaphor processing are conflicting, certain conceptualizations on semantic processing by the RH fit with data from both neurologically intact and RHD patients indicating a unique role for the RH in appreciating figurative meanings. For instance, the fine versus coarse semantic coding theory (Beeman, 1998) supplies a theoretical framework for the contribution of the RH to the processing of metaphorical meanings. According to the coarse semantic coding model, the RH seems to weakly activate broad semantic fields including peripheral, distant, and unusual semantic features whereas the LH activates a much smaller range of closely related concepts and central aspects of word meanings. For example, semantic processing in the LH may consist of initially activating all semantic information related to an ambiguous word, and then selecting the dominant, literal or contextually relevant meaning while inhibiting the subordinate, metaphoric or context-

ally non-relevant information (Anaki et al., 1998; Burgess & Simpson, 1988; Faust & Chiarello, 1998; Titone, 1998). In contrast, since broader semantic fields might be better able to capture certain types of semantic relations that depend on the overlap of distantly related meanings, the RH may rely on coarse semantic processing in activating and maintaining metaphoric meanings.

Understanding a metaphor requires the activation of distantly related concepts. When we encounter a metaphoric sentence like “*The lovers words are harp sounds*” (example of Rapp et al., 2004), *lovers words* and *harp sounds* are not close semantic associates. However, in the matched literal sentence “*The lovers words are lies*,” *lovers words* and *lies* are semantically related. According to the fine-coarse semantic coding theory, RH may have a special role in processing metaphoric language that relies on the activation of distant, unusual semantic relations. However, this dichotomy between closely and distantly related concepts is not perfectly analogous to the literal-metaphoric dichotomy. Thus, RH involvement in metaphor processing could be related to the novelty and unfamiliarity of the metaphoric sentences and not to the metaphoricity per se. This interpretation was tested by Schmidt and her colleagues (Schmidt, DeBuse, & Seger, 2007) in a study using the split visual field paradigm, in which centrally presented sentence stems were followed by three different endings: literal-unfamiliar (“*the busy secretary used string as a book mark*”), metaphor-unfamiliar (“*the close friends were a bag of toffees*”), and literal-familiar (“*Jane made a birthday cake topped with red frosting*”) as control endings. Another experiment examined hemispheric differences in processing more as compared to less familiar metaphors. Subjects were asked to decide whether the sentence was plausible or not. Results supported the claim that the RH is specialized for processing unfamiliar verbal stimuli that contain coarse semantic relationships, be they literal or metaphoric, whereas the LH is involved in processing familiar (literal) sentences. In addition, results showed a RH advantage for less familiar metaphors and LH advantage for more familiar metaphoric sentences. These results support previous findings (Bottini et al., 1994) of unique RH involvement in the processing of unfamiliar metaphoric sentences (both studies used the same metaphors and literal-unfamiliar sentences and the same task).

The importance of unfamiliarity and novelty in processing metaphoric language is a basic idea in the Graded Salience Hypothesis (GSH, Giora, 1997, Giora, 1999) that offers a theoretical framework focusing on the familiarity of linguistic stimuli rather than the literal-metaphoric distinction. According to the GSH, the degree of meaning salience of the linguistic stimuli determines the order by which meanings are retrieved. Salient meanings would be accessed before less salient meanings regardless of their literality or non-literality. Salient meanings refer to meanings that are coded in the mental lexicon, are highly familiar and hence easy to be accessed. This account is different from the standard pragmatic model (Grice, 1975), which

claims that literal meanings are activated before the metaphoric, nonliteral meanings, which are retrieved only after the literal meaning is found to be inappropriate. In the case of conventional metaphors (“*hard man*”) in which the metaphorical meaning (difficult) is more salient (Gibbs, 1980; Giora & Fein, 1999b) than the literal meaning (rigid), it is the figurative meaning that should be processed first, without having to access the less salient (literal) meaning (Gibbs, 1980; Giora & Fein, 1999a; Turner & Katz, 1997). Novel metaphors (“*conscience storm*”) demonstrate the opposite case since the metaphorical meaning of the novel metaphor (restless) is not coded in the mental lexicon and hence its meaning is nonsalient. According to the GSH it is the literal, rather than the intended metaphoric meaning of the utterance, that is more accessible (relying here on the salient meanings of its constituents). Hence, it is the literal meaning that would be accessed initially. Furthermore, the GSH predicts a selective RH involvement in the processing of novel, nonsalient meanings (such as novel metaphoric utterances), and LH involvement in the processing of conventional, salient meanings (such as conventional metaphors). Thus, in light of the GSH, predictions concerning the processing of literal and metaphorical linguistic material by the LH, the dominant hemisphere for language processing, or the RH are determined by the degree of this material’s salience.

According to the GSH, the conflicting evidence from previous research using functional brain imaging techniques to study the role of RH in metaphor processing could be related to the confounding effects of literality and salience. Thus, the results of the recent imaging study (Rapp et al., 2004) described above did not find supporting evidence for RH involvement in metaphor processing. This finding could have arisen if the newly created stimuli—which were not rated for familiarity—seemed familiar, and thus were best processed by the LH. The findings of another recent fMRI study (Mashal et al., 2005) support this explanation. Our results suggest that RH involvement in the processing of metaphoric expressions may be related to the salience of the linguistic expressions. In this study, subjects read two words expressions, which constituted literal expressions (“*walking shoes*”), familiar metaphorical expressions (“*iron fist*”), poetically novel metaphorical expressions (“*imagination caves*”), or unrelated (meaningless) word pairs (“*joke window*”). Results could not be attributed to the complexity of the linguistic stimuli (c.f., Bottini et al., 1994) since these stimuli consisted of word pairs and not of sentences. In addition, RTs for the novel metaphorical expressions and for unrelated word pairs were significantly longer than RTs for both the literal and the conventional metaphoric expressions, but the novel metaphors elicited higher activation than both of the other meaningful conditions in the RH, whereas the unrelated word pairs did not.

To sum up, the findings of recent behavioral (Anaki et al., 1998; Schmidt et al., 2007) and imaging researches

(Bottini et al., 1994; Jung-Beeman et al., 2004; Mashal et al., 2005; Sotillo et al., 2005) suggest that the RH may be involved in processing linguistic forms that require diffuse and less selective semantic activation and maintenance. Consequently, the RH may be particularly adept at using mutually remote elements of new linguistic combinations, a process that may lead to the more creative process or solution (Dorfman, Shames, & Kihlstrom, 1996). This putative RH ability for linguistic creativity might be crucial for processing ambiguous and metaphoric language and, particularly, for the processing of novel metaphoric expressions. The aim of the present study was to use the fMRI technology to identify brain areas involved in novel metaphor processing, and, specifically, brain areas that are reportedly active during tasks that require verbal creativity.

In the present study, 15 right-handed subjects read literal expressions, familiar metaphorical expressions, novel metaphorical expressions taken from poetry and unrelated words pairs, and decided what kind of semantic relation exists between the words: literal, metaphorical, or unrelated. We tested the hypothesis that the processing of novel metaphors relies on unique RH processing mechanisms. Based on recent fMRI studies (e.g., Eviatar & Just, submitted; Jung-Beeman et al., 2004; Mashal et al., 2005) we expected to find RH involvement, specifically in the right PSTS, for the processing of novel metaphors. By contrasting the novel metaphors with literal expressions and, specifically, with conventional metaphors (both conditions represent the salient meanings), we expected to find stronger activation for the novel metaphors in right PSTS. Contrasting the novel metaphors with conventional metaphors is the critical test of the present study's hypothesis since both types of expressions require the same response (i.e., metaphorically related). In addition, although both expressions are metaphoric they differ on the familiarity scale (conventional metaphors being highly familiar and novel metaphors being unfamiliar). Moreover, if the involvement of the right PSTS stems only from the unfamiliarity, nonsalience of the novel metaphors (as compared to conventional metaphors or literal expressions) this pattern of activation would not be found when the novel metaphors are contrasted with unrelated word pairs. Unrelated word pairs and novel metaphors are both unfamiliar (representing meanings which are not coded in our mental lexicon) and if direct comparison between them elicits activation in right PSTS then it can be deduced that familiarity is not the only factor which affects this activation. The right PSTS showed activation when subjects processed novel metaphoric sentences (Bottini et al., 1994), novel, nonsalient, metaphoric expressions (Mashal et al., 2005), novel ironic statements (Eviatar & Just, submitted), as well as when subjects solved creative verbal problems (Jung-Beeman et al., 2004). In addition to the right posterior/superior temporal gyrus our regions of interest (ROIs) include the left inferior frontal gyrus (IFG), which is known to be involved in semantic relative to nonsemantic tasks (Gabrieli, Poldrack, & Desmond, 1998), semantic selection (Eviatar & Just, submitted;

Keller, Carpenter, & Just, 2001; Kircher, Brammer, Andreu, Williams, & McGuire, 2001), and semantic selection among competing alternatives from semantic memory (Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997).

2. Materials and methods

2.1. Subjects

Fifteen healthy volunteers (ages 21–31; 8 males), native Hebrew speakers, participated. Participants were first year psychology students of Bar-Ilan university, and hence formed a relatively homogenous group of participants similar in terms of general intellectual level and educational background. All signed an informed consent form that was approved by the ethical committees of the Tel Aviv Sourasky Medical Center. In addition, 19 volunteers who did not participate in the fMRI study, aged 23–29, participated in a behavioral experiment outside the magnet. All subjects from both experiments were right handed, yielding a laterality quotient of at least +90 on the Edinburgh Inventory (Oldfield, 1971).

2.2. Stimuli

Stimuli included 96 pairs of words that formed four types of semantic relations: literal (*water drops*), conventional metaphoric (*bright student*), novel metaphoric (*pearl tears*) (mostly taken from poetry, the rest composed by the authors), or unrelated (*road shift*). Stimuli were all nouns and were balanced between conditions according to word frequency, concreteness (66, 64, 64, and 62.5%, for the novel metaphors, literal expressions, unrelated word pairs, and conventional metaphors, respectively), abstractness (34, 36, 36, and 37.5%, for the novel metaphors, literal expressions, unrelated word pairs, and conventional metaphors, respectively). Prior to the study, 20 judges who did not participate in either the fMRI or the behavioral studies were presented with a list of two word expressions and asked to decide if each expression is literally plausible, metaphorically plausible or unrelated. Expressions that were rated by at least 75% of the judges as metaphorically/literally plausible or unrelated were selected for use in the corresponding conditions.

Another group of 10 judges was presented with a list of only the metaphors rated as plausible in the first pretest, and were asked to rate their degree of familiarity on a 5 point familiarity scale ranging from 1 (highly unfamiliar) to 5 (highly familiar). Metaphoric expressions scoring less than 3 on the familiarity scale were selected for the study as novel metaphors (rating average 1.98), whereas those scoring above 3 on this scale were selected as conventional metaphors (rating average 4.67). In this way, we could distinguish between novel and conventional metaphors.

Thirty one additional judges were presented with the list of all the words (unpaired, and in random order) and asked to rate their degree of frequency on a 5 point frequency

scale ranging from 1 (highly infrequent) to 5 (highly frequent). The average frequency ratings were 3.38, 3.45, 3.67, and 3.79 for the unrelated word pairs, literal expressions, novel metaphors, and conventional metaphors, respectively. No significant difference was found between the four conditions ($F < 1$).

2.3. Instructions

Since linguistically naïve persons may have considerable difficulties making an explicit distinction between literal and metaphoric expressions, participants were trained to perform the same task on a different set of stimuli prior to the experiment. We explained them that the meanings of metaphorical expressions contain an interpretation, which lies beyond the individual meanings of the words. For example, the expression “sweet sleep” is metaphorical since the sleep is not really sweet (as opposed to “*sweet cake*”). We instructed them to pay attention to conventional metaphors, which seem literally related because of frequent daily use. We also informed them that some of the expressions are taken from poetry and that they might seem unfamiliar and meaningless (“*pearl tears*”) but still might have metaphorical meanings. The experimenter trained the participants in front of a computer screen, giving many examples, until the distinction between literally and metaphorically related expressions was clear.

2.4. MRI experimental procedure and task

The fMRI block design¹ paradigm consisted of 16 blocks of 15 s each, interleaved by blank periods of 15 s, and 15 s rest block at end, during which subjects viewed a fixation point on a gray background. Each condition block contained six pairs of words. These pairs of words included

familiar metaphoric expressions (conventional metaphors), novel metaphoric expressions, literal expressions, and unrelated word pairs, hence comprising four types of blocks (Fig. 1). Each stimulus was presented for 2100 ms followed by 400 ms blank. Each experimental condition appeared four times (out of 16 blocks) in each scan session in a way that balanced the order of conditions. The first 18 s (six repetitions) of the scan allowed for T2* equilibration effects, and were excluded from analyses. Consequently, the functional part of this experimental session lasted 513 s.

While participants were being scanned, they silently decided whether the two words in each pair were metaphorically related, literally related, or unrelated. Subjects were not informed that the different stimuli of each block belonged to the same type. To prevent subjects from automatically responding ‘metaphor related’, ‘literal related’, or ‘unrelated’, each block contained one distracter, i.e., an unrelated word pair in the conventional metaphor, novel metaphor, and literal conditions and a metaphoric expression in the unrelated condition. By asking subjects to explicitly decide what type of semantic relatedness exists between the two words, we were better able to track the brain areas directly involved in processing the basic type of semantic relation existed between the two words.

2.5. Behavioral experimental procedure and task

Nineteen different participants performed a semantic judgment task outside the magnet. They were asked to indicate by pressing one of three keyboard buttons whether the two words presented simultaneously at the center of a computer screen are related literally, metaphorically, or unrelated. The subjects were informed that some of the word pairs represent novel metaphoric expressions taken from poetry. The rate and order of presentation were identical for both the behavioral and fMRI experiments.

2.6. Imaging acquisition

Imaging measurements were performed on a GE 1.5T Signa Horizon LX 9.1 echo speed scanner (Milwaukee, WI) with resonant gradient echoplanar imaging system, located at the Wohl Institute for Advanced Imaging in the Tel Aviv Sourasky medical center. All images used a standard quadrature head coil. The scanning sessions included anatomical and functional protocols. Anatomical images were based on high resolution sagittal localizers acquired in the beginning of each scan. Twenty three contiguous axial T1-weighted slices, 4 mm thick, with 1 mm gap covered the whole brain. In addition, a 3D spoiled gradient echo (SPGR) sequence, with high resolution, was acquired for each subject, to allow for a volume statistical analysis of signal changes during the experiment and to facilitate later coordinate determinations. The functional T2*-weighted protocols included gradient echo planar imaging pulse sequence (TR/TE/flip angle = 3000/55/90) with FOV of 24 cm² and matrix size of 80 × 80, acquired in the same plane

¹ *Block design and covert responses:* Block design fMRI experiments confer considerable power to detect hemodynamic changes occurring in response to extended durations of repeated cognitive processes, in comparison to a “baseline” block in which at least one of the component cognitive processes is attenuated or eliminated. In essence, the continuous neural activity associated with sustained performance of a task allows hemodynamic response and associated BOLD signal to saturate. There are two significant disadvantages of block design. (1) The task and expected response are predictable, thus prone to potential confounds such as anticipation or other strategies that differ from the same task when performed unexpectedly (e.g., when not expecting a metaphor). In four types of blocks, we included one distracter (out of six stimuli) in each block, to reduce the predictability of responses. (2) Individual trials within a block cannot be compared, preventing specific analysis of data, e.g., by type of response produced (correct or incorrect). This problem is exacerbated by the lack of overt verbal responses (to avoid jaw and head movement), such that performance was not assessed on-line (we chose not to use button responses because pressing one of three buttons might require more attention and memory load or might lead also to head movement). However, in a debriefing session following the experiment all participants reported that they fully cooperated in performing the task as required, and the ability of subjects to perform the task with these stimuli was confirmed by extensive pre-testing (at least 75% accuracy rate) and a separate behavioral experiment conducted outside the magnet with different subjects.

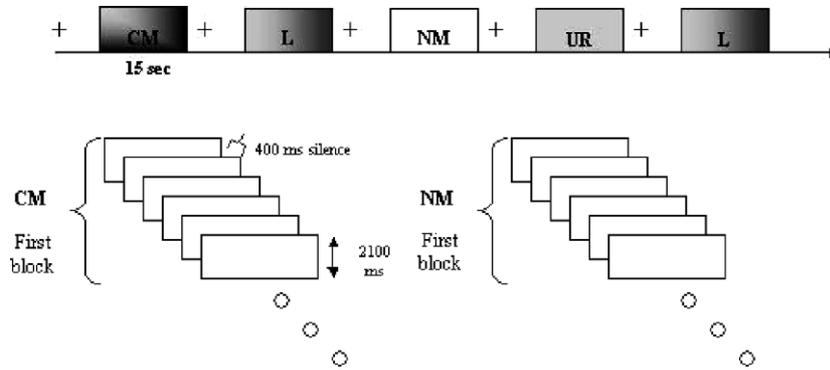


Fig. 1. Block design. Four types of experimental blocks were randomly presented for 15 s with 15 s of fixation between blocks: CM (Conventional Metaphors, i.e., *sweet sleep*); L (Literal expressions, i.e., *road crossing*); NM (Novel Metaphors, i.e., *desire batteries*) and UR (unrelated word pairs, *fuel rectangle*). Each experimental block consisted of six stimuli.

and slices. No evidence of structural abnormalities was found in any of the participants.

2.7. Data analysis

fMRI data were processed with BrainVoyager software package (version 4.9; Brain Innovation, Maastricht, The Netherlands). Prior to statistical tests, raw data were examined for motion and signal artifacts. We applied motion correction, (scans with head movement > 1.5 mm were rejected), high frequency temporal filtering (0.006 Hz), and drift correction. In addition, slice acquisition times were corrected by using sinusoid interpolation. Functional images were then superimposed on 2D anatomical images, and incorporated into 3D data sets through trilinear interpolation. The complete data set was transformed into Talaraich space (Talaraich & Tournoux, 1988). For the group analysis, boxcar predictors were defined for each condition and were convolved with the hemodynamic response function. A general linear model (GLM, Friston et al., 1995) was calculated for the group of 15 subjects for fixed effect analysis. The contrasts are described in Table 1 and Table 2.

2.8. Time course analysis for ROI's analysis

Our ROIs were defined anatomically by using sulci and gyri as landmarks: the pars opercularis (BA 44) in the inferior frontal gyrus (IFG, left and right) and the area near or at the posterior superior temporal sulcus between the superior temporal gyrus and the middle temporal gyrus BA 41/42 (PSTS, left and right). Our ROIs were functionally selected by calculating three-dimensional statistical parametric maps separately for each subject using general model in which all stimuli conditions were positive predictors and the blank as a negative predictor, with an expected lag of 6 s (account for the hemodynamic response delay). Then, time-courses of statistically significant voxels (threshold at $p < .0001$, uncorrected) were collected in each of the predetermined region of interest: left PSTS (BA 41/42) 300 voxels; right PSTS (BA 41/42) 200 voxels; left IFG (BA 44) 300 voxels; right IFG (BA44) 200 voxels. Individual averaged MR

signals were calculated from all epochs of the same condition per activated ROI. Signals were then transformed into percent signal changes relative to baseline signal. Significance tests were performed on the average percent signal change obtained within the cluster of a region for each condition over the whole epoch. Statistical analysis was performed using STATISTICA software (version 5).

3. Results

3.1. Behavioral data

3.1.1. Reaction times

Reaction times (RTs) were collected *outside* the magnet from 19 subjects who did not participate in the fMRI scan. As shown by (repeated measures) one-way ANOVA, subjects responded with different latencies to the four stimulus types (conventional metaphors, novel metaphoric expressions, literal expressions, and unrelated two word pairs) ($F(3, 54) = 5.57, p < .01$). Tukey's honest significant difference (HSD) post hoc comparisons revealed that participants responded more slowly to novel metaphors ($M = 1385$ ms, $SD = 205$ ms) than to both the conventional metaphors ($M = 1275$ ms, $SD = 200$ ms, $p < .05$) and the literal expressions ($M = 1261$ ms, $SD = 195$ ms, $p < .05$). In addition, participants responded more slowly to unrelated words pairs ($M = 1370$ ms, $SD = 227$ ms) than to literal expressions ($p < .05$) and slightly more slowly than they responded to conventional metaphors ($p = .07$). No difference between the literals and the conventional metaphors was found.

3.1.2. Accuracy

Subjects identified correctly 84.2, 87.2, 92, and 93.9% of the novel metaphors, conventional metaphors, literal expressions, and unrelated words pairs, respectively, and these accuracy differences were significant ($F(3, 54) = 7.55, p < .001$). Tukey's HSD post hoc comparisons revealed that subjects were significantly more accurate in identifying the unrelated words pairs than they were in identifying both the novel metaphors ($p < .001$), and the conventional metaphors ($p < .05$). Subjects were significantly more accurate in

Table 1
Greater activation for NM > UR, CM > UR, and L > UR

	BA	L/R	Talairach	# of voxels	t value
NM > UR					
Anterior insula	13	R	37, 18, 8	886	5.57
Thalamus		L	-6, -11, 13	692	4.47
Middle frontal gyrus	10	L	-37,45,16	623	3.85
Middle frontal gyrus	10	R	40,49,11	602	4.3
Anterior insula	13	L	-35, 18, 7	597	3.86
Inferior frontal gyrus	46	L	-46, 33, 14	568	3.96
Middle frontal gyrus	9	L	-36, 34, 32	499	3.73
Middle frontal lobe	46	R	49,22,25	490	3.75
Inferior parietal lobe	40	L	-40,-48,43	484	4.12
Anterior cingulate	32	L	-5, 31, 28	473	4.03
Middle temporal gyrus	21	L	-51, -46, 0	363	3.57
Inferior frontal gyrus	44	L	-52, 9, 21	333	3.48
Inferior frontal gyrus	44	R	52, 15, 10	298	3.2
Middle temporal gyrus	21	R	63, -30, -1	231	4.65
Posterior superior temporal sulcus	41/42	R	43, -22, 4	82	3.24
CM > UR					
Middle temporal gyrus	21	L	-50, -52, 2	1708	3.43
Inferior parietal lobe	19	L	-32, -70, 39	1172	4.95
Inferior frontal gyrus	46	R	42, 46, 7	588	3.97
Middle frontal gyrus	10	L	-37, 44, 17	566	4.05
Inferior parietal lobe	40	L	-41,-50,39	467	4.15
Middle frontal gyrus	10	R	40, 50, 10	466	3.84
Thalamus		L	-7, -11, 14	364	4.3
Anterior insula	13	L	-37, 16, 6	361	3.37
Middle temporal gyrus	21	R	61, -31, -3	352	3.36
Anterior insula	13	R	36, 21, 9	347	3.97
Middle frontal gyrus	9	L	-35, 38, 32	290	3.49
Inferior frontal gyrus	44	L	-47, 8, 17	279	3.49
Inferior frontal gyrus	46	L	-42, 36, 8	224	3.87
Inferior frontal gyrus	44	R	52, 15, 10	195	3.79
L > UR					
Inferior parietal lobe	19	L	-32, -70, 39	1189	5.05
Inferior parietal lobe	40	L	-40, -48, 41	791	4.94
Middle frontal gyrus	10	R	40, 51, 19	768	4.9
Middle frontal gyrus	10	L	-36,45,21	720	4.33
Anterior insula	13	R	37, 18, 8	644	4.23
Middle temporal gyrus	21	R	55, -40, -1	618	4.19
Middle temporal gyrus	21	L	-52, -47, -1	429	4.02
Thalamus		L	-5, -11, 6	293	4.11
Inferior frontal gyrus	44	R	52, 15, 10	248	4.25
Inferior frontal gyrus	44	L	-46, 9, 21	188	2.51*
Inferior frontal gyrus	46	L	-44, 36, 8	173	3.33
Anterior insula	13	L	-34, 13, 6	157	3.45

All areas showing greater activation in 15 healthy subjects while they decide which semantic relation exists between the two words versus deciding that the two words are unrelated. The table presents the number of significant voxels ($p_{\text{uncorrected}} < .05$) for three contrasts: novel metaphors minus unrelated words (NM > UR); conventional metaphors minus unrelated words (CM > UR); literal expressions minus unrelated words (L > UR). Broadman areas, the center of the activation in Talairach coordinates, and t value indicating the significance of the contrast (all at $p < .001$) are also presented. PSTS, posterior superior temporal sulcus. Thalamus refers to the medial dorsal nucleus. * $p < .01$.

recognizing the literal expressions than they were in recognizing novel metaphors ($p < .01$). These results were consistent with the results of the pre-test. Novel metaphors were selected if at least 75% of the judges considered them metaphorically plausible and the subjects in the study identified 84.2% of the novel metaphors as metaphorically plausible.

3.1.3. Types of errors

From among the incorrect responses, 90% of error responses to the novel metaphors were that they were unrelated; 10% of the error responses were that they were

literal expressions. For conventional metaphors, 78% of the errors were that they were literal expressions and 22% were that they were unrelated word pairs. For literal expressions, 72% of the errors were that they were metaphors and 28% of the errors were that they were unrelated word pairs. From among the incorrect responses to the unrelated words pairs, 58% of the errors were viewed as literal expressions and 42% as metaphors. These results demonstrate a symmetrical pattern of errors between the literal and the conventional metaphors, which comprise the salient stimuli. Errors made for the novel metaphors

Table 2
Greater activation for NM > L, CM > L, NM > CM

	BA	L/R	Talairach	# of voxels	<i>t</i> value
NM > L					
IFG	44	L	−45,30,19	157	4.6
PSTG	42	R	60,−50,14	85	4.48
IFG	44	R	40,28,13	48	3.84
MFG	46	L	−48,16,33	33	4.28
Anterior cingulate	32	Middle	2,24,29	82	3.85
CM > L					
Postcentral parietal lobe	40	R	51,−28,53	227	5.12
PSTS	39	L	−51,−57,24	102	4.3
IFG	44/45	L	−44,29,−6	81	4.6
NM > CM					
PSTS	40	R	49,−29,4	113	4.16
IFG	44	R	47,21,20	103	3.38
MFG	46	L	−45,32,22	47	3.86

Number of significant voxels ($p_{\text{uncorrected}} < .01$) for three contrasts: novel metaphors minus literal expressions (NM > L); conventional metaphors minus literal expressions (CM > L); novel metaphors minus conventional metaphors. Broadman areas, right (R) or left (L), the center of the activation in Talairach coordinates, and *t* value indicating the significance of the contrast (all at $p < .001$) are also presented. PSTS/G, posterior superior temporal sulcus/gyrus; IFG, inferior frontal gyrus; MFG, middle frontal gyrus.

indicate that misidentified stimuli were mostly considered, as expected, as unrelated words pairs.

3.2. Group analysis of fMRI data

We contrasted each meaningful stimulus (i.e., novel metaphors, conventional metaphors, and literal expressions) separately with the unrelated stimuli. Each contrast elicited activation in bilateral frontal areas, more pronounced in the LH. The results are summarized in Table 1. The opposite contrast (unrelated words pairs > meaningful stimuli) revealed no significant activation.

The contrast of novel metaphors minus literal expressions resulted in fewer and smaller active brain regions, as expected, than the contrast novel metaphors minus unrelated words pairs, and includes mainly bilateral frontal areas. Clusters with more than 20 significant voxels at threshold $p < .01$ (uncorrected) include, in order of size: left IFG, right posterior superior temporal gyrus, right IFG, left middle frontal gyrus (MFG), and left + right anterior cingulate (Table 2).

The contrast conventional metaphors minus literal expressions resulted in different brain regions: right post-central parietal lobe, left PSTS, and left IFG (Table 2).

The interesting contrast, novel metaphors minus conventional metaphors (Fig. 2) revealed clusters at right PSTS, right IFG, and left MFG (Table 2).

3.3. ROI analysis

Average percent signal change was analyzed by two-way repeated measures ANOVA for the 15 subjects with hemisphere (LH/RH) and stimulus type (conventional metaphors/novel metaphors/literal expressions/unrelated word pairs) as factors in left IFG (means Talairach coordinates $\pm SD$'s: -42.6 ± 2 , 11.6 ± 6.5 , and 5 ± 3) and its right homologue (42 ± 3.2 , 21.8 ± 4.1 , and 5.7 ± 5.4). Results

revealed a main effect of stimulus type $F(3,42)=4.78$, $p < .01$. Tukey's least significant difference (LSD) post hoc comparisons revealed in left IFG (BA44) statistically significant greater activation for the conventional metaphors than for the unrelated word pairs ($p < .05$), marginally significant greater activation for conventional metaphors than for literal expressions ($p = .068$), and greater activation for the novel metaphors than for the unrelated word pairs ($p = .051$). LSD's revealed in the right IFG (BA44) statistically significant greater activation for the novel metaphors than for the unrelated word pairs ($p < .05$), and greater activation for the conventional metaphors than for the unrelated word pairs ($p < .01$). The hemisphere main effect was also significant ($F(1,14)=4.79$, $p < .05$). Tukey's LSD post hoc analysis revealed greater activation for the conventional metaphors in the LH than in the RH ($p < .05$) and greater activation for the unrelated words pairs in the LH than in the RH ($p = .053$).

Twelve subjects showed significant activation for all task conditions over rest in right PSTS (49.1 ± 4.3 , -28.9 ± 6.3 , and 4.4 ± 2.7). These 12 subjects showed a significant main effect of stimulus type ($F(3,33)=3.15$, $p < .05$). They showed significantly stronger activation for novel metaphors than for the literal word pairs ($p < .05$). In addition, they showed stronger activation for the novel metaphors than for unrelated word pairs ($p < .05$). They showed no effect of stimulus type ($p = .21$) in Left PSTS (-46.2 ± 3.9 , -32.3 ± 8.7 , and 3.9 ± 3.2).

4. Discussion

The aim of the present study was to explore the brain substrates of metaphor processing and particularly to study how saliency and novelty modulate the contributions of the metaphor processing. The stimuli used in the present study were two word utterances: literal expressions, conventional

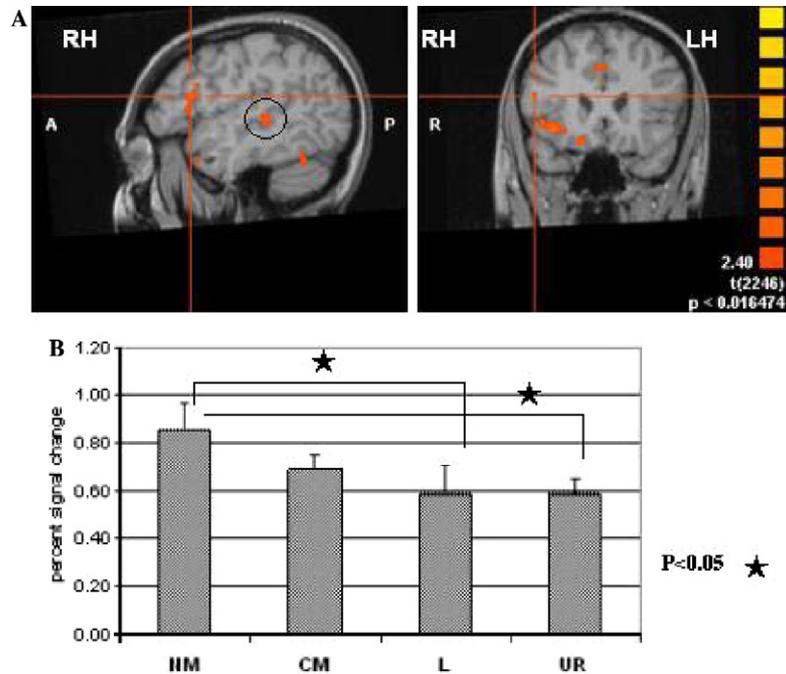


Fig. 2. Novel metaphors versus conventional metaphors. (A) Significant regions of activation for novel metaphors minus conventional metaphors in the right PSTS (black circle) and right IFG (red cross) obtained from 15 subjects, $p < .05$ uncorrected. (B) Significant greater percent signal change for novel metaphors (NM) than for both literal expressions (L) and unrelated word pairs (UR) obtained from 12 subjects in right PSTS. CM, conventional metaphors.

and novel metaphors, and unrelated word pairs. Subjects were asked to decide which kind of semantic relation exists between the two words (literal, metaphoric, or unrelated). Based on the graded salience hypothesis (GSH, Giora, 1997, 2002, 2003), we expected to find, in addition to left lateralized brain regions, unique involvement of the RH in processing nonsalient metaphoric meanings, but not in processing conventional salient metaphoric meanings, which are familiar and coded in the mental lexicon. Furthermore, the processing of novel metaphors might serve as an indication of verbal creativity, since, to combine the two words into a novel and meaningful expression (“*conscience storm*”), one has to create novel semantic connections between remotely associated words. Thus, our study may have some implications for the contribution of the RH to specific processes underlying verbal creativity.

Processing meaningful linguistic expressions such as novel metaphors, conventional metaphors, and literal expressions requires the integration of the meanings of two words into a coherent and meaningful expression, beyond the search for semantic relations that occurs for both related and unrelated word pairs. By contrast, processing unrelated words pairs involves searching for a connection, but no integration of meanings across the two words. For related pairs, successful semantic integration of the two words into a meaningful expression differs across the stimulus types. The meanings of the literal expressions and the conventional metaphors are familiar and coded in the mental lexicon, i.e., their meanings are salient, although the conventional metaphors (“*iron fist*”) contain implicated meanings (the fist is not made of iron), whereas the literal pairs (“*broken glass*”) do not. Contrary to

those familiar expressions, the meaning of the novel metaphors (“*pearl tears*”) are not coded in the mental lexicon and thus, their processing requires the establishment of novel, creative semantic relations.

Our results obtained from both the group and ROI analysis of the fMRI data provide evidence for a selective RH involvement in the processing (and perhaps the generation) of novel, nonsalient metaphoric meanings. It seems that the processing of novel metaphoric expressions requires the involvement of the right PSTS and left and right IFG. This right lateralized activation is specific to the novel metaphors but not to the unrelated word pairs although both constitute unfamiliar utterances. Unrelated word pairs share common features with novel metaphoric expressions: both are unfamiliar and both involve distant semantic relationships and hence both require the process of searching for meaning. This similarity is reflected in the very similar reaction times for the unrelated word pairs (UR) and the novel metaphoric expressions (NM), however, the process of searching for meanings is not reflected in terms of identical pattern of brain activation. Actually no significant stronger activation was found for unrelated word pairs as compared to novel metaphors (as well as to the other stimulus types). According to the results obtained from the group analysis, stronger activation for the novel metaphors than for both the conventional metaphors and literal utterances was found in right PSTS and right IFG. This pattern of stronger activation in right PSTS for the novel metaphors than for the literal utterances was further supported by the ROI analysis. One interpretation for the stronger activation for NM than UR expressions, specifically in the

right PSTS, is that the two words constructing the unrelated word pairs involve distantly semantic relationships that do not allow for the identification of overlapping semantic fields (Beeman, Friedman, Grafman, Perez, & Diamond, 1994; Beeman, 1998). This lack of semantic overlap for the unrelated word pairs results in weak brain activation as compared to the activation elicited by NM (which contain overlapping semantic fields). Another possible explanation is that the online construction of the meaningful, novel connections takes place in the right PSTS, and hence strong activation in this area was not found for the unrelated word pairs. Thus, the results suggest that any set of words bearing remote semantic relationships, be they novel metaphors or literal expressions, would lead to similar patterns of brain activation. Our literal expressions were familiar and closely related and hence we did not observe strong activation for this condition in the right PSTS.

Processing the salient meaning of the conventional metaphors as compared to the literal expressions resulted in higher activation level in left classical language areas (PSTS, IFG), and right postcentral parietal lobe (Table 2). Although, both types of stimuli constitute the familiar, salient, lexicalized meanings, our results obtained from the ROI analysis (also) indicate that left IFG (BA44) is more activated when subjects processed the metaphorical meaning as compared to processing the literal meaning of an expression. This result might reflect the higher cognitive demand required for the selection of abstract metaphorical meaning while ignoring the literal interpretation of the conventional metaphors (Gerensbacher & Robertson, 1999). The enhanced activation in left IFG for the conventional metaphors (“*iron fist*”) than for the literal expressions might have also resulted from the selection of the salient features of the vehicle (selecting the firmness but not the color of the iron) to compare these features to those of the topic (Glucksberg, 1998). Both explanations suggest that processing conventional metaphors requires an additional lexical selection process, which seems to be subserved by the left IFG (Keller et al., 2001) and are thus consistent with the GSH (Giora, 2003), which predicts LH involvement in processing salient meanings.

The processing of the two types of metaphoric expressions (conventional and novel metaphors) elicited different patterns of activation, although both of them relied on two common brain regions, left IFG and right IFG. The left IFG was activated when both the novel metaphors and the conventional metaphors were contrasted with literal expressions in the group analysis (see Table 2). In addition, the ROI analysis revealed a main effect for stimulus type, i.e., stronger activation for the novel and the conventional metaphors vs. the unrelated word pairs, in the left IFG. Moreover, according to the ROI analysis, the right IFG also showed stronger activation for both the novel and the conventional metaphors vs. the unrelated word pairs. In contrast, the right PSTS was uniquely activated when the novel metaphors were compared with the literal expressions and the unrelated word pairs [and to conventional meta-

phors, see Table 2]. However, activation in this area did not differ between the conventional metaphors and the other stimulus types. Thus, we suggest that the right PSTS may have a special role in associating two distantly related words into novel expressions.

The experimental task used in the present study, i.e., determining whether the expression is literal, metaphoric or unrelated, requires comprehension, but in addition it also requires some rather complex judgment processes (such as attention and forced-choice decision) that are not utilized in online processing. Metalinguistic tasks, similar to that of the present study, which required the subjects to attend to specific features of the stimuli and that is not necessarily part of language processing, are widely used in neuroimaging researches (e.g., Bottini et al., 1994). In light of this limitation future studies should confirm that the observed differences occur during processing, in the absence of such judgments.

Evidence from other brain imaging studies also suggests a special role for the right PSTS (or PSTG) in generating novel, unfamiliar, connections between words. In a recent fMRI study (Mashal et al., 2005) we used Principal Components Analysis to analyze brain activations resulting from the processing of the nonsalient meanings of novel metaphoric expressions (i.e., “*wisdom dust*”) compared with those resulting from the processing of the salient meanings of conventional metaphoric expressions (i.e., “*sweet sleep*”), and literal expressions (i.e., “*broken glass*”). Results indicated that the right posterior superior temporal sulcus (PSTS), the homologue of Wernicke’s area, recruits a special network which is involved in the processing of two word novel metaphoric expressions as compared to conventional metaphors and literal expressions. The PSTG was also activated when subjects solved creative verbal problems (Jung-Beeman et al., 2004) especially with insight. In this fMRI study subjects viewed a triad of words (*sauce, crab, pine*), then produced a solution word (*apple*) that could form a familiar compound with each of three previously presented words (*applesauce, crab apple, pine apple*). About half the time they solved problems, subjects did so with insight, marked by a distinctive feeling of Aha! When subjects solved these problems (with or without insight), neural activity increased in the right posterior STS. The primary brain area showing increased activity when subjects solved the problems with insight, compared to when they solved them without insight, was the right anterior STS. This suggests that when people successfully integrate very distant associations, RH temporal areas are heavily involved. Another fMRI study (Eviatar & Just, submitted) found significantly greater activation in the right superior and middle temporal gyri for the novel ironic statements than for the literal statements. In this study, subjects read two-sentence stories followed by critical statements that were either literal, familiar metaphoric or novel ironic sentences. The ironic meanings of the statements (“*Great weather for a picnic*”) following the context (“*Tom and Mike planned to go on a picnic. In the morning it was raining very hard*”) in Eviatar’s study represent stimuli with nonsalient meanings. The processing

of novel metaphoric meanings as well as insight verbal problem solving might reflect processes underlying verbal creativity. Both require the construction of remote, unusual, unfamiliar associations, which may rely on a common neural network, which includes the right PSTS.

The processing of novel metaphoric expressions used in the Mashal et al. (2005) study might reflect processes underlying verbal creativity. One aspect of creative thinking involves associating remote elements into a novel but useful (interpretable) combination (Mednick, 1962). According to Mednick (1962, p.221) “the more mutually remote the elements of the new combination, the more creative the process or solution.” Thus, verbal creativity could be defined as the ability to recognize or construct novel, nonsalient, connections or associations between words, to integrate their meanings and create plausible expressions. Processing novel metaphoric expressions could serve as one example for verbal creativity. Another example of a task that requires verbal creative thinking ability is the “dyads of triads” (DOT) test, developed by Bowers, Regehr, Balthazard, and Parker (1990), which is based on the Remote Associates Test, (RAT, developed by Mednick, 1962). In this test, subjects are asked to find a solution word (*match*), which is associated with the three previous presented words (*strike, same, tennis*). The words in this triad are semantically divergent, since the solution word creates different meanings with each of the three given words.

Two recent behavioral studies used a similar experimental paradigm to explore RH role in verbal creativity (Faust & Kahana, 2002; Faust & Lavidor, 2003). The difference between the two hemispheres in the scope of word meaning activation and maintenance may also be relevant for the ability to summate activation from several, semantically divergent single word primes followed by an ambiguous target word. In both studies, participants viewed laterally presented ambiguous target words that were preceded by two types of multiple word primes. Convergent primes were related to a single meaning of the ambiguous target word; Divergent primes were related to two different, incompatible meanings of the target word. When subjects viewed the ambiguous target words (e.g., second) in the RVF-LH, they benefited most from semantically convergent primes (i.e., “minute, watch, time”). When they viewed targets in the LVF-RH, they benefited most from semantically divergent primes (i.e., “minute, first, time”). These results corroborate previous findings showing that during word recognition, the RH activates a broader range of related meanings than the LH, including alternate meanings of ambiguous and metaphorical words. By summing activation for seemingly incongruous elements, the RH may be critically involved in at least one important component of verbal creativity.

Our results show that the processing of novel metaphoric expressions requires the involvement of the left IFG and left MTG. Left IFG and left MFG were both activated when we contrasted the novel metaphors with the literal expressions. Furthermore, the left MFG was activated during the novel vs. conventional metaphors contrast in the group analysis

(in fact it was the only left lateralized brain region activated in this contrast). The left IFG is consistently evoked during semantic tasks and, specifically, during the selection of relevant features from a set of competing alternatives (Gabrieli et al., 1998; Thompson-Schill et al., 1997). The activation of the left IFG seems to be important since the understanding of novel metaphors requires the association of the “topic” of the metaphor with the “vehicle.” The involvement of the left IFG is consistent with stronger activation in left IFG when subjects perform a valence judgment task (i.e., positive or negative connotations) while they read metaphoric sentences as compared to literal sentences (Rapp et al., 2004). Our results are also consistent with results indicating left IFG and right PSTS are part of a special neural network recruited for the processing of novel metaphors but not for the processing of either conventional or literal expressions (Mashal et al., 2005).

To sum up, our results indicate that the cooperation of right (PSTS and IFG) and left (IFG and MFG) brain regions is required for the process of attributing novel, creative, meanings to two word expressions. Stronger activation in the right PSTS for the novel metaphors than for the literal utterances points to the special role of this brain region in the construction of novel semantic connections. This finding is consistent with the GSH, which predicts RH involvement in processing nonsalient meanings and is also consistent with the fine-coarse coding theory, which suggests that the RH activates distantly related word meanings. In addition, the understanding of novel metaphoric expressions used in the present study seems to have some implications for verbal creativity in general and is thus recommended as a method of exploring the neuropsychological processes underlying verbal creativity.

Acknowledgments

Support for this work was provided by a grant from the binational scientific foundation (BSF) to Miriam Faust and Mark Jung-Beeman, Grant # 2003317.

References

- Anaki, D., Faust, M., & Kravetz, S. (1998). Cerebral hemispheric asymmetries in processing lexical metaphors. *Neuropsychologia*, *36*, 353–362.
- Beeman, M. (1998). Coarse semantic coding and discourse processing. In M. Beeman & C. Chiarello (Eds.), *Right hemisphere language processing: Perspectives from cognitive neuroscience* (pp. 255–284). Mahwah, NJ: Erlbaum.
- Beeman, M., Friedman, R. B., Grafman, J., Perez, E., & Diamond, S. et al. (1994). Summation priming and coarse semantic coding in the right hemisphere. *Journal of Cognitive Neuroscience*, *6*, 26–45.
- Bottini, G., Corcoran, R., Sterzi, R., Paulesu, E. S. P., Scarpa, P., Frackowiak, R. S. J., & Frith, C. D. (1994). The role of the right hemisphere in the interpretation of the figurative aspects of language: A positron emission tomography activation study. *Brain*, *117*, 1241–1253.
- Bowers, K. S., Regehr, G., Balthazard, C. G., & Parker, K. (1990). Intuition in the context of discovery. *Cognitive psychology*, *22*, 72–110.
- Brownell, H. H., Simpson, T. L., Bihrl, A. M., Potter, H. H., & Gardner, H. (1990). Appreciation of metaphoric alternative word meanings by left and right brain damaged patients. *Neuropsychologia*, *28*, 375–383.

- Burgess, C., & Simpson, G. (1988). Cerebral Hemispheric mechanisms in the retrieval of ambiguous word meanings. *Brain and Language*, 3, 86–103.
- Coulson, S., & Wu, Y. C. (2005). Right hemisphere activation of joke-related information: An event-related potential study. *Journal of Cognitive Neuroscience*, 17(3), 494–506.
- Coulson, S., & Williams, R. W. (2005). Hemispheric asymmetries and joke comprehension. *Neuropsychologia*, 43, 128–141.
- Dorfman, J., Shames, V. A., & Kihlstrom, J. F. (1996). Intuition, Incubation, and Insight: implicit cognition in problem solving. In G. Underwood (Ed.), *Implicit cognition* (pp. 257–296). Oxford England: Oxford University Press.
- Eviatar, Z. Just, M. (submitted). Brain correlates of discourse processing: an fMRI investigation of irony and metaphor processing.
- Faust, M., & Chiarello, C. (1998). Sentence context and lexical ambiguity resolution by the two hemispheres. *Neuropsychologia*, 3, 827–836.
- Faust, M., & Kahana, A. (2002). Priming summation in the cerebral hemispheres: evidence from semantically convergent and semantically divergent primes. *Neuropsychologia*, 40, 892–901.
- Faust, M., & Lavidor, M. (2003). Convergent and divergent priming in the two cerebral hemispheres: Lexical decision and semantic judgment. *Cognitive Brain Research*, 17, 585–597.
- Faust, M. E., & Gernsbacher, M. A. (1996). Cerebral Mechanisms for suppression of inappropriate information during sentence processing. *Brain and Language*, 53, 234–259.
- Friston, K., Holmes, A. P., Worsley, K., Poline, J. B., Frith, C., & Frackowiak, R. S. J. (1995). Statistical parametric maps in functional imaging: A general linear approach. *Human Brain Mapping*, 2, 189–210.
- Gabrieli, J. D. E., Poldrack, R. A., & Desmond, J. E. (1998). The role of left prefrontal cortex in language and memory. *Proc. Natl. Acad. Sci. USA*, 95(3), 906–913.
- Gerrensbacher, M. A., & Robertson, R. R. (1999). The role of suppression in figurative language processing. *Journal of pragmatics*, 31(12), 1619–1630.
- Gibbs, R. W. (1980). Spilling the bean on understanding and memory of idioms in conversation. *Memory and Cognition*, 8, 449–456.
- Giora, R. (1997). Understanding figurative and literal language: The graded salience hypothesis. *Cognitive Linguistics*, 7, 183–206.
- Giora, R. (1999). On the priority of salient meanings: Studies of literal and figurative language. *Journal of Pragmatics*, 31, 919–929.
- Giora, R. (2002). Literal vs. figurative language: Different or equal? *Journal of Pragmatics*, 34, 487–506.
- Giora, R. (2003). *On our mind: Salience, context and figurative language*. New York: Oxford University Press.
- Giora, R., & Fein, O. (1999a). On understanding familiar and less familiar figurative language. *Journal of Pragmatics*, 31, 1601–1618.
- Giora, R., & Fein, O. (1999b). Irony: Context and salience. *Metaphor and Symbol*, 14, 241–257.
- Giora, R., Zaidel, E., Soroker, N., Batori, G., & Kasher, A. (2000). Differential effects of right-and left- hemisphere damage on understanding sarcasm and metaphor. *Metaphor And Symbol*, 15, 63–83.
- Glucksberg, S. (1998). Understanding metaphors. *Current Directions in Psychological science*, 17(2), 39–43.
- Grice, H.P., 1975. Logic and conversation. In P. Cole and J. Morgan (Eds.) *Speech acts: Syntax and Semantics*, 3, 41–58. New York Academic Press.
- Jung-Beeman, M. J., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R., Reber, P. J., & Kounios, J. (2004). Neural activity when people solve verbal problems with insight. *Plos Biology*, 2, 500–510.
- Keller, T. A., Carpenter, P. A., & Just, M. A. (2001). The neural bases of sentence processing: A fMRI examination of syntactic and lexical processing. *Cerebral cortex*, 11(3), 223–237.
- Kircher, T. T. J., Brammer, M., Andreu, N. T., Williams, S. G. R., & McGuire, P. K. (2001). Engagement of right temporal cortex during linguistic context. *Neuropsychologia*, 39, 798–809.
- Kutas, M., & Besson, M. (1999). Electrical signs of language in the brain. In C. Fuchs & S. Robert (Eds.), *Language diversity and cognitive representations* (pp. 159–178). Philadelphia: John Benjamins Publishing company.
- Mashal, N., Faust, M., & Hendler, T. (2005). The role of the right hemisphere in processing nonsalient metaphorical meanings: Application of Principal Components Analysis to fMRI data. *Neuropsychologia*, 43(14), 2084–2100.
- McDonald, S. (1996). Clinical insights into pragmatic theory: Frontal lobe deficits and sarcasm. *Brain & Language*, 68, 486–506.
- Mednick, S. A. (1962). The associative basis of the creative process. *Psychological review*, 69, 220–232.
- Oldfield, D. J. (1971). The assessment of handedness: The Edinburgh Inventory. *Neuropsychologia*, 9, 97–113.
- Pynte, J., Besson, M., Robishon, F. H., & Poli, J. (1996). The time course of metaphor processing: An event-related potential study. *Brain and Language*, 55, 293–316.
- Rapp, A. M., Leube, D. T., Erb, M., Grodd, W., & Kircher, T. T. J. (2004). Neural correlates of metaphor processing. *Cognitive Brain research*, 20, 395–402.
- Rinaldi, M. C., Marangolo, P., & Baldassari, F. (2004). Metaphor processing in right brain-damaged patients with visuo-verbal and verbal material: A dissociation (re)considered. *Cortex*, 40, 479–490.
- Schmidt, G.L., DeBuse, C.J., Seger, C.A. (2007). Right Hemisphere Metaphor Processing? characterizing the Lateralization of Semantic Processes. *Brain and Language*, 100, 127–141.
- Sotillo, M., Carretti, L., Hinojosa, J. A., Manuel, M., Mercado, F., Lopez-Martín, S., & Albert, J. (2005). Neural activity associated with metaphor processing: Spatial analysis. *Neuroscience Letters*, 373, 5–9.
- Stringaris, A. K., Medford, N.C., Giampetro, V., Brammer, M.J., David, A. S. (in press). Deriving meaning: Distinct neural mechanisms for metaphoric, literal and non-meaningful sentences.
- Talaraich, J., & Tournoux, P. (1988). *A co planner stereotaxic atlas of a human brain*. Stuttgart: Theime Verlag.
- Tartter, V. C., Gomes, H., Dubrovsky, B., Molholm, S., & Stewart, R. V. (2002). Novel metaphors appear anomalous at least momentarily: Evidence from N400. *Brain and Language*, 80, 488–509.
- Titone, D. (1998). Hemispheric differences in context sensitivity during lexical ambiguity resolution. *Brain and language*, 65, 361–394.
- Thompson-Schill, S. L., D’Esposito, M., Aguirre, G. K., & Farah, M. J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A reevaluation. *Proceeding of the National Academy of Science*, 94, 14792–14797.
- Turner, N. E., & Katz, A. N. (1997). Evidence for the availability of conventional and of literal meaning during the processing of proverbs. *Pragmatics and Cognition*, 5, 203–237.
- Weylman, S. T., Brownell, H. H., Roman, M., & Gardner, H. (1989). Appreciation of indirect requests by left and right damaged patients. The effects of verbal context and conventionality of wording. *Brain and language*, 36, 580–591.
- Winner, E., & Gardner, H. (1977). The processing of metaphor in brain damaged patients. *Brain*, 100, 717–729.
- Zaidel, E., Kasher, A., Soroker, N., & Batori, G. (2002). Effects of right and left hemisphere damage on performance of the “Right Hemisphere Communication Battery”. *Brain and language*, 80(3), 510–535.