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Research report

Hemispheric differences in processing the literal interpretation of idioms: Converging evidence from behavioral and fMRI studies

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A B S T R A C T

The present study examined the role of the left (LH) and right (RH) cerebral hemispheres in processing alternative meanings of idiomatic sentences. We conducted two experiments using ambiguous idioms with plausible literal interpretations as stimuli. In the first experiment we tested hemispheric differences in accessing either the literal or the idiomatic meaning of idioms for targets presented to either the left or the right visual field. In the second experiment, we used functional magnetic resonance imaging (fMRI) to define regional brain activation patterns in healthy adults processing either the idiomatic meaning of idioms or the literal meanings of either idioms or literal sentences. According to the Graded Salience Hypothesis (GSH, Giora, 2003), a selective RH involvement in the processing of nonsalient meanings, such as literal interpretations of idiomatic expressions, was expected. Results of the two experiments were consistent with the GSH predictions and show that literal interpretations of idioms are accessed faster than their idiomatic meanings in the RH. The fMRI data showed that processing the idiomatic interpretation of idioms and the literal interpretations of literal sentences involved LH regions whereas processing the literal interpretation of idioms was associated with increased activity in right brain regions including the right precuneus, right middle frontal gyrus (MFG), right posterior middle temporal gyrus (MTG), and right anterior superior temporal gyrus (STG). We suggest that these RH areas are involved in semantic ambiguity resolution and in processing nonsalient meanings of conventional idiomatic expressions.

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1. Introduction

Although, traditionally, left-hemisphere (LH) perisylvian regions were considered to be the areas crucial for language in the brain, a growing body of research indicates that several language processes, mainly those within the semantic and pragmatic domains, require the cooperation of both hemispheres, and may in fact be characterized by predominant right hemisphere (RH) involvement. Thus, behavioral and imaging studies show unique RH involvement in semantic ambiguity resolution and in the understanding of figurative aspects of language (e.g., Anaki et al., 1998; Brownell et al., 1990; Bottini et al., 1994; Faust and Chiarello, 1998; Mashal et al., 2005; Mashal et al., 2007; Pobric et al., 2008; Eviatar and Just, 2006). The present study investigated LH and RH involvement in processing alternative meanings of ambiguous idiomatic sentences and, specifically, the role of the RH in understanding the literal meanings of idiomatic sentences that can be interpreted both idiomatically and literally.

The claim that the RH plays a major role in the processing of metaphoric language (Bottini et al., 1994; Brownell et al., 1990; Brownell et al., 1984; Rinaldi et al., 2004; Schmidt et al., 2007; Winner and Gardner, 1977; Pobric et al., 2008), ironic statements (Eviatar and Just, 2006) and idiomatic expressions (Burgess and Chiarello, 1996; Van Lancker and Kempler, 1987; Kempler et al., 1999) is widely accepted, although some studies showed bilateral hemispheric involvement (Ahrnes et al., 2007) or failed to support unique RH involvement in processing metaphoric language (Stringaris et al., 2007; Rapp et al., 2004; Lee and Dapretto, 2006). For instance, in one study right hemisphere damaged (RHD) patients and left-hemisphere damaged (LHD) patients were presented with familiar idioms (''*she's got him eating out of her hands*'') along with four pictures for each idiom (Kempler et al., 1999). One picture was related to the correct idiomatic interpretation (a man showering a woman with gifts and affection), two foils, which were related to individual words within the idiomatic sentence, and a fourth picture showing the opposite meaning of the idiomatic expression (a man ignoring a woman). Subjects were asked to select one drawing that matches each sentence read aloud by the examiner. The RHD group performed significantly worse on this idiom comprehension task than did the LHD group.

The results of another study using repetitive transcranial magnetic stimulation (rTMS) failed to find evidence that the RH is critical for comprehending idiomatic expressions (Papagno et al., 2002). In this study, healthy subjects were presented with a written (opaque) idiomatic sentence and were asked to choose between two pictures: one depicting the correct idiomatic interpretation of the sentence and another that corresponds to its literal interpretation. When subjects performed this task, left temporal (Broadman area 22) rTMS increased the latencies and decreased the accuracy of responses, compared to a baseline condition (no rTMS) and compared to right hemisphere rTMS.

Two main theories have addressed the issue of idiom comprehension. The lexical representation model (Swinney and Cutler, 1979) suggests that idiomatic expressions are stored and retrieved from the mental lexicon in the same way that long words are accessed. This means that both interpretations, related to either the literal or the idiomatic meanings, are accessed when the first word is encountered. However, since the process of accessing the idiomatic meaning is faster than the process of computing the literal meaning, the idiomatic meaning would be retrieved first. Alternatively, the ''configurational hypothesis'' (Tabossi and Zardon, 1995; Cacciari and Tabossi, 1988) proposes that idiomatic expressions may be mentally presented and processed as configurations of words and their meanings become activated only after a word in a key position has been identified. The 'key position' refers to the point at which the idiomatic meaning emerges. More specifically, the meaning of an idiomatic expression is encoded according to the strength (weights) of the connections between words (lexical nodes). For example, the connections between the words in the idiomatic expression ''*kick the bucket*'' are weighted more heavily than the connections between the words in the matching literal sentence ''*kick the jar*''.

Linguistic theories of idiom processing, such as the lexical representation model and the ''configurational hypothesis'', address the time course of idioms processing but do not point to specific brain-regions' involvement. However, a more general linguistic theory, termed the Graded Salience Hypothesis (GSH, Giora, 1997, 1999, 2002, 2003; Giora et al., 2000) addresses both the time course of meaning activation and ''where'' in the brain these processes take place. According to the GSH, the degree of meaning salience of the linguistic stimuli determines the order by which meanings are retrieved. A meaning is salient if it is coded and has marked prominence due to factors such as conventionality, frequency, familiarity, and prototypicality. Meanings could vary on the continuum between salient meanings (i.e., coded meanings) and nonsalient meanings (i.e., noncoded meanings). Coded meanings that are high on those factors are salient meanings. Coded meanings, low on such factors, are less salient. Noncoded, i.e., novel meanings, constructed on the fly, are nonsalient. According to the GSH, salient meanings are easier to access than less salient ones, regardless of literality or non-literality. Nonsalient meanings will require more complex and inferential processes, regardless of literality or non-literality.

The idiomatic meaning of a familiar idiomatic expression (''*he is out in left field*'') is salient because it is not compositional – it is not derived from the meanings of the individual words that make it up (*his location is in a left field*) – but listed as a whole in the mental lexicon (*he is really quite lost*) (see also Laurent et al., 2006). Its literal interpretation, however, is nonsalient, because it is compositional – it is based on the interrelations of the meanings of its individual words which endow an idiomatic expression with novelty (Giora et al., 2004). Thus, if the RH specializes in linguistic reinterpretation (Brownell et al., 1986; Chiarello, 1991), the GSH predicts stronger RH involvement in the comprehension of nonsalient (literal) interpretations of familiar idiomatic expressions and stronger LH involvement in the comprehension of their salient (idiomatic) meanings (see Giora, 2003; Giora et al., 2000). The GSH is consistent with the fine versus coarse semantic coding model (Beeman, 1998; Jung-Beeman, 2005). According to this model, RH weakly activates ''broad semantic fields'' whereas the LH activates ''narrow semantic fields'', consisting of dominant, central semantic features. Consequently, the LH is suitable for selecting a single interpretation and inhibition of irrelevant interpretations. In contrast, RH activates large but diffuse semantic fields (through the coarse coding of information) that include peripheral, subordinate information. Thus, the RH is more sensitive than the LH to distant semantic relations.

Both the GSH (Giora, 2003) and the fine versus coarse semantic coding model (Beeman, 1993) offer theoretical explanations for the observed differences between the cerebral hemispheres in processing ambiguous items. Many studies using ambiguous words showed different patterns of response times when accessing the dominant and the subordinate meanings of ambiguous words. Among the firsts were Burgess and Simpson (1988) who pointed to the role of the RH in lexical ambiguity resolution. They reported that both LH and RH show facilitation for dominant meanings of homographs (e.g., *pen*) at short stimulus onset asynchronies (SOA, 35 msec). However, at the long SOA (750 msec), the LH showed decreased access for the subordinate meanings, whereas facilitation for the subordinate meanings (*cage*) increased in the RH. Anaki et al. (1998) investigated semantic priming for literal (*mosquito*) and metaphorical (*insult*) associates of ambiguous words (*stinging*) presented to either the LVF or RVF. Results demonstrated priming effects for metaphorically related primes presented to either visual field at a short SOA (200 msec), whereas, at the longer SOA of 800 msec, this effect was observed only for primes presented to the LVF/RH.

Thus, a major difference between the LH and RH semantic processing is that the RH maintains alternative interpretations whereas the LH selects (contextually) appropriate meanings of ambiguous words and inhibits inappropriate meanings. This ability of the RH to maintain different word meanings makes it suitable for revising initial interpretations as well as for resolving ambiguities, specifically when subsequent context is inconsistent with the selected interpretation (Chiarello, 1991).

Evidence from neurologically impaired subjects supports the notion that the RH is specialized for processing subordinate, connotative meanings of words (e.g., Brownell, 1988; Brownell et al., 1984). Grindrod and Baum (2003) showed that RHD patients activate more dominant meanings, regardless of context. In this study, LHD and RHD individuals and non-brain damaged (NBD) control subjects were presented with ambiguous words in biased sentences (e.g., *After writing a long message, he looked at the CARD* [greeting *vs* playing card]) and performed a cross-modal lexical decision task. The major findings were that LHD nonfluent aphasic patients were primed by both meanings regardless of context at the short inter-stimulus intervals (ISI, 0 msec) and were not primed by any meaning at the long ISI. In contrast, RHD patients showed small priming effects for more frequent meanings at both the long (750 msec) and the short ISI. These results suggest that the RH may be involved in ambiguity resolution by activating both dominant and subordinate meanings. Ambiguous idioms, similar to ambiguous words, contain dominant, salient (idiomatic) meanings and subordinate, nonsalient (literal) meanings. This similarity between ambiguous words and ambiguous idioms raises the question whether the processing of ambiguous idioms involves RH processing mechanisms as was observed for ambiguous words. Thus, it could be argued that the literal interpretations of idioms are analogous to the subordinate meanings of ambiguous words in that both meanings are less frequent and are retrieved at a late stage, following the retrieval of the dominant meaning (idiomatic meanings and dominant meanings for the idioms and ambiguous words, respectively).

Behavioral data regarding the involvement of the RH in processing nonsalient as compared with salient meanings are remarkably scarce. In one study (Faust and Mashal, 2007) participants were presented with four types of word pairs and asked to perform semantic judgments on the second word of each pair that was presented to the RVF/LH or LVF/RH. The two words formed four types of semantic relations: literal (*problem resolution*), and conventional metaphoric (*transparent intention*) – both representing the salient; coded meanings, and novel metaphoric, (*conscience storm*) and unrelated (*wisdom wash*) word pairs – both representing the nonsalient interpretations. Results indicated that novel metaphoric two-word expressions were processed faster and more accurately when the second word of each pair was presented to the LVF/RH than when it was presented to the RVF/LH. This RVF advantage was not found in either accuracy or response latency for the literal and unrelated word pairs.

The few brain imaging studies that addressed the "localization" question, i.e., which brain regions are involved in processing nonsalient meanings, found support for the predictions of the GSH and coarse coding model. A recent fMRI study (Mashal et al., 2005) compared brain activation when subjects processed the nonsalient meaning of novel, metaphoric, two-word expressions ("*conscience storm*") to when they processed the salient meanings of conventional metaphoric ("*sweet sleep*"), and conventional literal expressions ("*broken glass*"). The right posterior superior temporal gyrus (pSTG), the homologue of Wernicke's area, was particularly involved in the processing of novel metaphoric expressions. Another fMRI study (Eviatar and Just, 2006) found significantly greater activation in the right superior and middle temporal gyri when subjects comprehended novel ironic statements than when they comprehended literal statements. In this research, subjects read two-sentence stories followed by target statements that were either literal, familiar metaphoric, or novel ironic sentences. Note that only the ironic interpretation of the statements ("*Great weather for a picnic*") following the ironically biasing context ("*Tom and Mike planned to go on a picnic. In the morning it was raining very hard*") are nonsalient. These results also support the claim that the RH is uniquely involved in the processing of nonsalient, novel meanings (for similar findings from a lesion study see Giora et al., 2000).

The aim of the present study was to test the hypothesis that subordinate, nonsalient linguistic interpretations of idioms involve RH processing mechanisms. As noted above, divided visual field experiments demonstrated facilitation for dominant meanings but not for subordinate meanings in the LH whereas RH showed facilitation for subordinate meanings of ambiguous words for the long SOA. Idioms with a plausible literal interpretation make up a good case to study because of the salience differences between their idiomatic meanings and their literal interpretations. Thus, the present study investigated the involvement of the RH in processing the nonsalient, subordinate (literal) interpretation of idiomatic expressions. In order to test the prediction of the GSH

(Giora, 2003) that the RH is involved in processing nonsalient interpretations, and also the claims that the RH has special role in ambiguity resolution, we conducted two experiments. In the first experiment we examined hemispheric differences in accessing the literal versus the idiomatic meaning of idioms. Participants read idioms and performed a lexical decision task to target words related to either the idiomatic (*afraid*), or the literal (*temperature*) meaning of idioms (*he got cold feet)* presented to the left or to the right visual field (LVF/RH, RVF/LH, respectively). Our main prediction was that responses to the literal interpretation of idioms will be faster in LVF/RH than in the RVF/LH. In the second experiment we used fMRI technology in order to more specifically identify RH regions involved in the processing of nonsalient meanings of idiomatic sentences. Thus, we compared brain regions activated while subjects were thinking about the literal interpretation as opposed to the salient (idiomatic) meaning of idioms. Based on the GSH (Giora, 2003), the fine versus coarse semantic coding model (Beeman, 1998), and findings showing that RH has a special role in ambiguity resolution, we expected to find greater activation in right lateralized brain areas for processing the literal as compared to the idiomatic meaning of idioms and LH activation in processing familiar, salient meanings. Specifically, we expected to find stronger brain activation for the literal interpretation of idioms in at least one of two different areas in the right superior temporal gyrus (STG), the anterior/medial part (aSTG) or the posterior part (pSTG). The right aSTG may be involved in semantic integration (St. George et al., 1999; Jung-Beeman, 2005), particularly across novel semantic relations. Such processing might be required for solving verbal insight problems (Jung-Beeman et al., 2004) as well as for interpreting idiomatic expressions literally. In addition, evidence from fMRI studies indicates that the right pSTG is involved in the processing of nonsalient meanings of novel metaphoric expressions (Mashal et al., 2005, 2007; Faust and Mashal, 2007; Pobric et al., 2008), unfamiliar metaphoric sentences as compared to literal sentences (Bottini et al., 1994), and nonsalient meanings of novel ironic sentences (Eviatar and Just, 2006).

2. Materials and methods

2.1. Pretests

Idioms selection began with an initial pool of 200 ambiguous idioms. Stimuli consist of 3–4 words ambiguous idioms (i.e., idioms with literal and idiomatic interpretations) and literal sentences, each one followed by a target word. In order to determine the salient meaning of each idiom, two pretests were performed.

In the first pretest (run by Giora et al., 2004), 32 native speakers of Hebrew were presented with a list of two hundred ambiguous sentences (such as ‘‘*do not make waves*’’), which have both a nonliteral (‘‘*do not cause problems*’’) and a literal (‘‘*do not make waves in the water*’’) interpretation. They were told that they were presented with nonliteral items and were asked to rate the familiarity of the sentences on a seven points familiarity scale ranging from one (highly non-familiar) to seven (highly familiar). The 50 sentences scoring highest (average 6.34) on the familiarity scale were selected.

In the second pretest, another group of 15 native speakers of Hebrew (aged 22–36) were presented with the 50 ambiguous sentences. For each sentence, participants were asked to write down the first meaning that comes to mind. All of the participants (100%) wrote the same nonliteral meaning and hence we concluded that, for all of these sentences, the idiomatic meaning is more salient than the literal meaning. An additional set of 25 literal sentences was constructed. The literal sentences differed from the idioms in one or two words (i.e., ‘‘kick the bucket’’ *vs* ‘‘kick the jar’’). All the sentences were balanced between the experimental conditions according to syntactic structure and number of words.

The third pretest aimed to correctly select the target words that are compatible with either the literal or idiomatic meaning of the idioms or literally related to the literal sentences. In order to do so, nine judges rated the target words on a three-point compatibility scale ranging from one (low compatible) to three (high compatible). The average rates on the compatibility scale were 3.0, 2.95, and 2.95 to the words idiomatically related to the idiomatic meaning of the idioms, the words literally related to the literal interpretation of the idioms, and those literally related to the literal interpretation of sentences, respectively.

Target word frequencies were rated on a normalized five-point frequency scale ranging from one (highly infrequent) to five (highly frequent), using an internet database (http://word-freq.mscc.huji.ac.il/index.html) for Hebrew words. One way ANOVA for the three types of target words showed that they did not differ in frequency ($F(2,38) = 1.14$, $p > .3$).

Thus, the final stimulus pool consists of 50 ambiguous idioms and 25 literal sentences. Twenty-five idioms were followed by a literally related target word (i.e., ‘‘tie the knot’’ – *rope*), twenty-five idioms were followed by an idiomatically related target word (i.e., ‘‘give someone the cold shoulder’’ – *unfriendly*), and twenty-five literal sentences were followed by a literally related target word (‘‘give someone the cold drink’’ – *glass*). In addition, a set of 30 filler sentences (idioms and literal sentences) of similar length followed by nonword targets was also created. These nonword targets were matched in length to the word targets.

These idioms and sentences were used in the fMRI experiment. In a similar procedure of pretests, another set of 26 idioms was selected in order to expand the pool for the behavioral experiment. Thus, in order to come up with this larger set and the related target words, additional pretests, similar to those described above were conducted. Thus, 10 native Hebrew speakers were presented with a list of 30 additional idioms and were asked to write down the first meaning that comes to mind. All of the participants wrote the same idiomatic meaning and hence we concluded that the idiomatic meaning is more salient than the literal meaning.

In order to select target words that are compatible with either the literal or the idiomatic meaning of the idioms, 12 Hebrew native speakers rated the target words on a three-point compatibility scale ranging from one (low-compatibility) to three (high compatibility). Two target words with an average score of two or less on the compatibility scale were dropped from the stimulus pool. The average rates on the compatibility scale were 2.52, 2.45, 2.67, and 2.55 to target words idiomatically related to the meaning of the idioms presented to the LVF or RVF, and to target words literally related to the idioms presented to the LVF or RVF, respectively.

Target words were matched for length and frequency. Word frequencies of the target words were rated on a normalized five-point frequency scale ranging from one (highly infrequent) to five (highly frequent), using an internet database (http://word-req.mscc.huji.ac.il/index.html) for Hebrew words. One way ANOVA for the target words showed that they did not differ in frequency ($F(3,54) = .85$, $p > .4$).

2.2. *Experiment 1: behavioral divided visual field experiment*

2.2.1. *Aim*

The aim of this experiment was to investigate the RH sensitivity to nonsalient, literal interpretations of ambiguous idioms.

2.2.2. *Participants*

Thirty-two healthy volunteers, students at the psychology department in Bar-Ilan University, aged 20–27, native Hebrew speakers, participated in the study. All participants were right handed, yielding a laterality quotient of at least +90 on the Edinburgh Inventory (Oldfield, 1971). They received course credits for their participation.

2.2.3. *Stimuli*

Stimuli consisted of 76 idioms, followed by target words presented either to the RVF/LH or the LVF/RH. From those 76 idioms, 38 were followed by target words related to the idiomatic meaning of the idiom and 38 idioms were followed by target words related to the literal meaning of the idiom. In addition, a set of 60 filler sentences (idioms and literal sentences) of similar length followed by nonword targets was also constructed. These nonword targets were matched for length to the targets word with 15 filler sentences per condition. Cell means were thus based on 19 trials per condition per participant.

2.2.4. *Procedure*

A $2 \times 2 \times 2$ repeated measures design with relatedness (literally related, idiomatically related), visual field (right, left), and target type (word, nonword) as independent variables was used. Idioms were centrally presented followed by the target word displayed 2.8 degrees to the right or to the left of a centrally presented "+". Targets subtended, on average, 1.90 degrees of horizontal visual angle (.7 degrees vertical) at a viewing distance of 60 cm. The participant placed his/her right index finger between two keys on the computer keyboard and waited for a focusing signal (200 msec duration), which was presented centrally and indicated the onset of a trial. Immediately following the disappearance of the focusing signal, an idiom appeared for 2000 msec. Participants were instructed to read the idioms silently. Next, a focusing signal reappeared for 350 msec followed by a target stimulus (word or nonword) that was presented to the RVF or to the LVF for 180 msec. The focusing signal remained on the screen until the end of the target stimulus presentation, to ensure full fixation (i.e., 530 msec fixation duration). At the beginning of the session, participants were instructed to focus on the central "+" and not to move their eye while it was displayed. Participants were instructed to indicate as rapidly and as accurately as possible whether the target stimulus was a word or a nonword by lifting and moving the right index finger from the middle position to the right or left keys. The next trial began with a fixation point of 2000 msec following offset of target word. The session began with a practice list, consisting of eight idioms not used in the experimental lists. Stimuli were presented using the SuperLab software (version 2.0; http://www.cedrus.com).

2.2.5. *Results*

A 2×2 repeated measures analysis of variance with visual field (left, right) and relatedness type (idiomatically *vs* literally) was performed on correct RTs for target words (Fig. 1). Mean percentages of correct responses were 90.15%, 94.11%, 91.02%, 91.02% for the Id_Lit presented to the RVF/LH, LVF/RH, and Id_Id presented to the RVF/LH, LVF/RH, respectively, with no significant difference between conditions ($p > .1$).

The main effect of visual field was significant. Participants responded more quickly to target words presented to LVF/RH (mean = 715.59 msec; SD = 154.03) than to RVF/LH (751.48 msec, 168.58), $F(1,31) = 5.88$, $p < .05$. A main effect of relatedness type of target words was also significant, $F(1,31) = 9.48$, $p < .01$. Participants responded more quickly to target words literally related (720.19 msec; 159.92) than idiomatically related (746.89 msec; 163.89) to the idioms. The interaction between visual field and type of relatedness was significant ($F(1,31) = 5.59$, $p < .05$). Scheffe post hoc analysis revealed that target words literally related to the idioms were identified faster when they were presented to the LVF/RH (688.53; 148.51) than when they were presented to the RVF/LH (751.84; 166.89). No difference response times was found between the hemispheres in lexical decisions to target words related to the idiomatic meaning of idiomatic expressions (742.65, 184.9 in the RH; 751.13, 142.69 in the LH).

2.2.6. *Conclusions*

Results of Experiment 1 showed that RTs to LVF/RH presented target words related to the literal meaning of ambiguous idioms were faster than to RVF/LH presented target words. However, no difference was found between the LH and RH in lexical decisions to target words related to the idiomatic

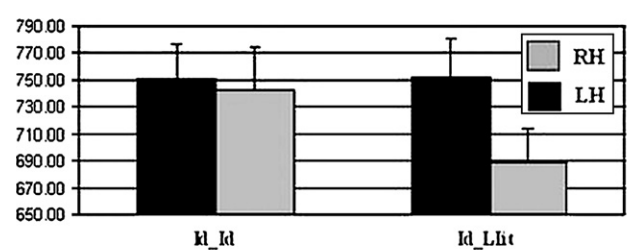

Fig. 1 – RTs (ms) and SEs for the two types of the related target words presented to the LVF/RH or RVF/LH. Id_Id = target words related to the idiomatic meaning of idiom; Id_Lit = target word related to the literal interpretation of the idiom.

meaning of idiomatic expressions. These results suggest that the RH is more sensitive than the LH to nonsalient, literal interpretations of ambiguous idioms.

2.3. *Experiment 2: fMRI*

2.3.1. *Aim*

The aim of this experiment was to identify RH regions involved in the processing of nonsalient interpretations, i.e., the literal interpretations of ambiguous idioms.

2.3.2. *Participants*

Fourteen healthy volunteers (aged 21–31 years; 8 males), native speakers of Hebrew, were recruited for the study. All participants were right handed, yielding a laterality quotient of at least +90 on the Edinburgh Inventory (Oldfield, 1971). All signed an informed consent form that was approved by the ethical committees of the Tel Aviv Sourasky Medical Center. All subjects were trained to perform the task outside the magnet and after confirming that they understood the task and are willing to participate in the scanning experiment, their brains were scanned.

2.3.3. *Stimuli*

Stimuli were 3–4 words ambiguous idioms (50) and literal sentences (25) that were described in the Section 2.1.

2.3.4. *fMRI experimental procedure and task*

The stimuli were presented in a block design fashion. Each block contained five sentences consisting of 3–4 words, which were either ambiguous idioms (i.e., ‘‘get off your high horse’’) or matching literal sentences (i.e., get off your high ladder). Each stimulus was presented for 3200 msec, followed by 400 msec of a fixation cross. Participants were instructed to perform one of two different tasks: to process the sentence nonliterally, i.e., to think about the idiomatic meaning of the sentences (do not act like you are better than everyone else), to process the sentence literally, i.e., to think about the literal meaning of the idiom (*get off the horse*), or to process the corresponding literal sentence literally (*get off the ladder*). Each of the three experimental conditions appeared five times (out of 15 blocks) in each scan session and the order of presentation was counterbalanced. The epochs (18 sec for each block) were separated by 15 sec during which participants viewed a fixation point on a gray background. These fixation blocks (rest condition) provided the baseline for measuring the level of brain activation. Prior to each block, instructions on how to process the sentences, idiomatically or literally, appeared on the screen for 3 sec. The first 18 sec (six repetitions) of the scan were rejected to allow for T2 equilibration effects. Consequently, the functional part of this experimental session lasted 570 sec. The visual stimuli were projected to subjects inside the magnet tube using Presentation software (Neurobehavioral Systems, Inc; http://nbs.neuro-bs.com) through a LCD video projector (Epson MP 7200), viewed via a mirror located in front subjects’ eyes.

2.3.5. *Data acquisition*

Imaging was performed on GE 1.5 T Signa Horizon LX 9.1 echo speed scanner (Milawaukee, W1) 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 localizer acquired in the beginning of each session. Twenty-three contiguous axial T1-weighted slices, 4 mm thick with 1 mm gap, were prescribed, covering the whole brain. In addition, a 3D spoiled gradient echo (SPGR) sequence, with high resolution, was acquired for each subject, in order 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 cm^2 and matrix size of 80×80. No evidence of structural abnormalities was found in any of the participants.

2.3.6. *Data analysis*

fMRI data was processed with BrainVoyager software package (version 4.9; Brain Innovation, Maastricht, The Netherlands). Prior to statistical analysis, raw data were examined for motion and signal artifacts. To allow for T2 equilibrium effects, the first six images of each functional scan were rejected. We applied motion correction, (scans with head movement >1.5 mm were rejected), high frequency temporal filtering (.006 Hz), and drift correction. In addition, slice acquisition times were corrected 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 and Tournoux, 1988). Statistical assessment of brain activation was based on random effect analysis. A general linear model (GLM, Friston et al., 1995) was calculated for the group of 14 subjects for random effect analysis by convolving boxcar predictors for each condition with the hemodynamic response function. Subsequently, contrasts comparing brain activation induced by salient versus nonsalient meanings were performed.

2.3.7. *Results*

2.3.7.1. Group analysis imaging data. We first compared the brain activation obtained for idiomatic processing of idioms (Id_Id) to that for literal processing of the matching literal sentences (Lit_Lit), using random effects model. Three areas of the LH all showed greater activation during idiomatic processing of idioms than during literal processing of literal sentences: inferior frontal gyrus (IFG), middle temporal gyrus (MTG) (Fig. 2A) and Thalamus (Fig. 2B) at $p < .01$, uncorrected.

We then compared the literal processing of idioms (Id_Lit) to the idiomatic processing of idioms. At a high threshold of $p < .0001$ (uncorrected, $t > 6$), greater activation was observed for processing the nonsalient, literal interpretation than for processing the salient, idiomatic meaning of the idioms only in the RH middle temporal gyrus (MTG) (40, −69, 25). At the $p < .001$ level (uncorrected, $t > 4.4$) significant activation was also found at the anterior part of the right superior temporal gyrus (STG) (50, −12, 6) near the auditory cortex (Fig. 3A) and at the left and right anterior insula ((−33, −13, 11); (34, −14, 10),

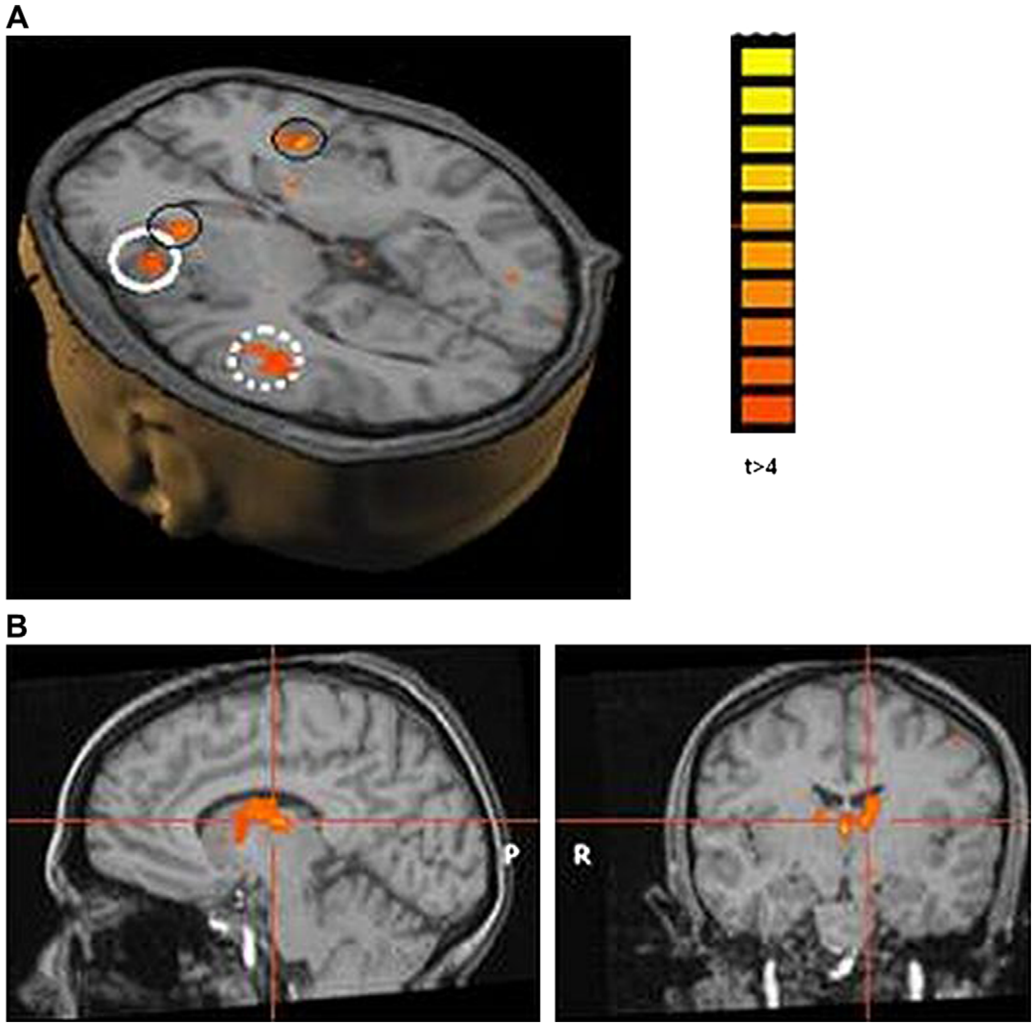

Fig. 2 – Group activation map ($n = 14$) for Id_Id more than Lit_Lit at the level of $p < .01$ (uncorrected) obtained from random effect analysis. (A) Axial view of clusters represent significant activation: white dashed circle present the left MTG; white circle present the left IFG; black circles present the insula. (B) Sagital and coronal view (left and right pictures, respectively) at left Thalamus (red cross). Note that the LH is in the left side of the picture.

respectively). The opposite contrast, i.e., Id_Id > Id_Lit, detected one cluster above the threshold of $p < .001$ ($t > 4.4$), in the left IFG (−45, 14, 20) BA45 (Fig. 3B).

Processing the literal meanings of idioms (Id_Lit) and processing the literal meanings of matched literal sentences both require subjects to perform literal interpretation. The contrast Id_Lit > Lit_Lit detected significant activation above the threshold of $p < .001$ (uncorrected, $t > 4.4$) only at the left sublobar caudate body ((−6, 13, 10); Fig. 3C) and the opposite contrast Lit_Lit > Id_Lit did not reveal significant activation above the threshold $p < .001$ ($t > 4.4$).

In order to find which areas are more sensitive to the less salient meaning of the sentence (i.e., literal processing of ambiguous idioms) than to the salient meanings (i.e., either processing nonliteral meanings of the idioms or processing the literal meanings of literal sentences), we performed a conjunction analysis.

The conjunction analysis of Id_Lit > Lit_Lit and Id_Lit > Id_Id did not reveal significant activation at the level of $p < .001$ or $p < .0001$ (as applied for the separate contrasts). Since conjunction analyses find out the overlapping regions among a set of contrasts, it is more difficult to obtain activation at the level of the individual contrasts. However, when we examined the data using a more lenient threshold of ($p < .01$, $t > 3.6$), significant activation was found in three small clusters at the right parietal lobe, precuneus (8, −76, 42), 36 voxels; right middle frontal gyrus (MFG) (44, 19, 40), 14 voxels; and right middle temporal gyrus (MTG) (50, −56, 3), 8 voxels.

3. Conclusions

Results of the conjunction analysis revealed that when literal interpretations of idioms were processed, neural activity increased in right lateralized brain regions consisting of the precuneus, middle frontal gyrus and posterior middle temporal gyrus. Direct comparison between the processing of idiomatically and literally related meanings of idioms revealed increased activity in the right anterior superior temporal gyrus and the right middle temporal

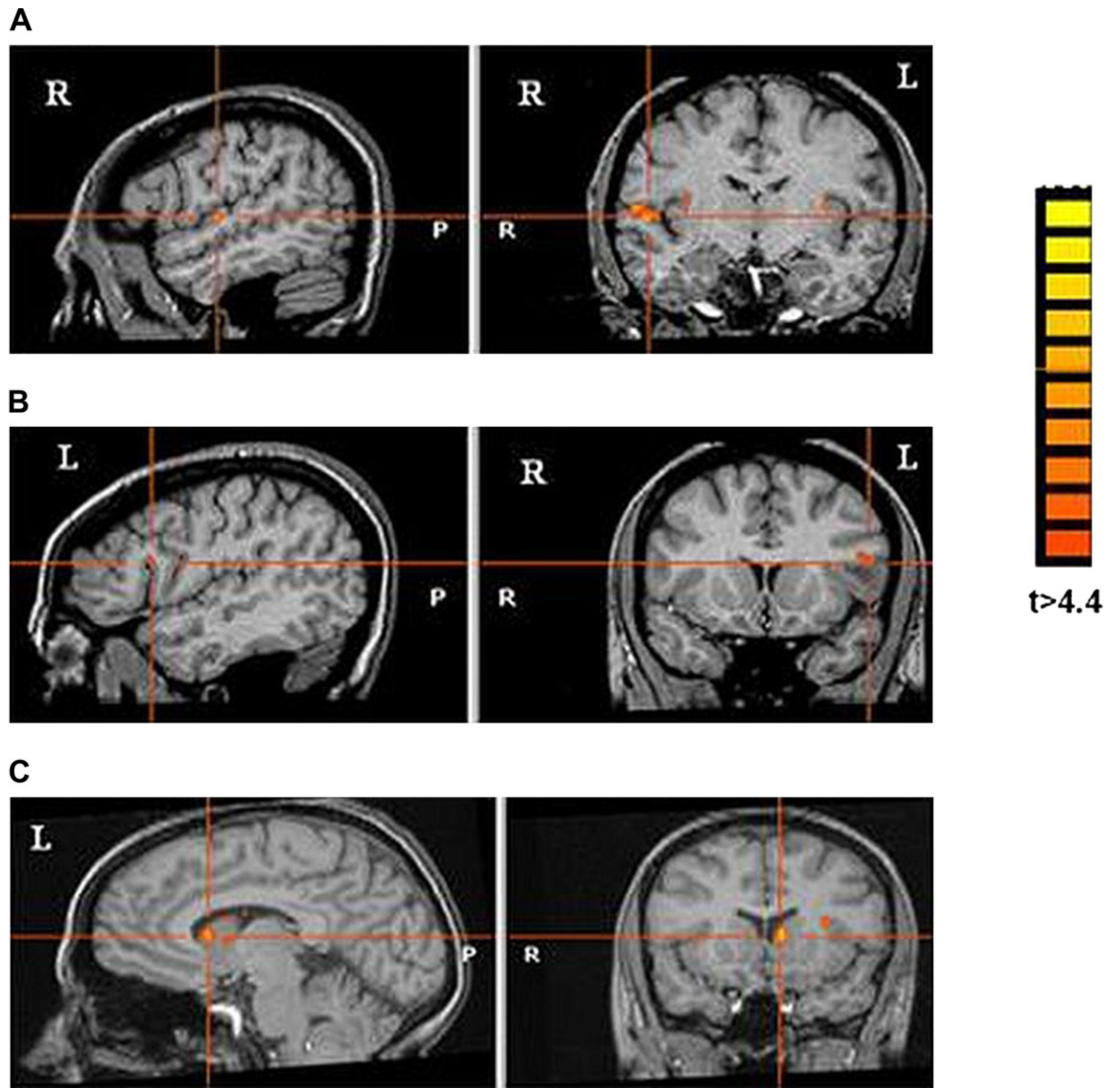

Fig. 3 – Random effect analysis of fourteen subjects obtained from the contrast. (A) Id_Lit > Id_Id revealed significant cluster at the anterior/medial part of right STG BA 21/22 (red cross) and for the opposite contrast. (B) Id_Id > Id_Lit (red cross at left IFG BA45). (C) Id_Lit > Lit_Lit detected significant activation above the threshold of $p < .001$ (uncorrected, $t > 4.4$) only at the left sublobar caudate body.

gyrus. However, more activation was found in areas of the LH, including the inferior frontal gyrus, when participants processed the salient, idiomatic meanings of ambiguous idioms than when they processed their nonsalient, literal meanings.

4. Discussion

The aim of the present study was to examine hemispheric involvement in processing the nonsalient, literal, interpretations of idiomatic expressions as compared to their salient, idiomatic, meanings. Based on the GSH (Giora, 1997, 2002, 2003; Giora et al., 2000), which predicts that nonsalient interpretations will be processed in the RH while salient meanings will primarily engage the LH, it was predicted that processing the nonsalient (plausible) literal interpretations of idioms (Id_Lit), would recruit RH regions, whereas processing salient meanings, i.e., accessing the lexicalized, idiomatic meanings of idioms (Id_Id) or the literal interpretations of conventional literal sentences (Lit_Lit), will mainly activate the LH. In order to test these predictions, two experiments, a behavioral and an fMRI study, were conducted. In Experiment 1, subjects performed lexical decisions to target words presented either to the LVF/RH or to the RVF/LH. As expected, Id_Lit targets were processed faster in the LVF/RH than in the RVF/LH. However, no differences in response times were found between the two hemispheres for Id_Id target words. In Experiment 2 we applied the random effect model to the fMRI data obtained from 14 subjects when processing either the literal or the idiomatic meanings of idioms or the literal meanings of literal sentences. The direct comparison, Id_Lit > Id_Id, revealed greater activation in right lateralized brain regions consisting of the anterior part of the STG (aSTG), posterior MTG, and left and right insula. In addition, the opposite contrast, i.e., Id_Id > Id_Lit, revealed stronger activation in the left IFG.

Our results provide evidence for RH advantage in processing literal, nonsalient interpretations of idioms with plausible literal meanings. Experiment 1 examined which hemisphere is involved in processing the subordinate, nonsalient meanings of ambiguous idioms. The most interesting finding of this experiment, which used divided visual fields presentation, was the significant interaction between visual field and type of target word. Thus, target words that were literally related to idioms were accessed faster in the LVF/RH than in the RVF/LH. These findings are in line with the predictions of the GSH indicating that the processing of nonsalient meanings involves RH mechanisms.

Our results thus extend findings of previous studies that presented ambiguous words with or without sentential context. Most studies that tested RTs for ambiguous words presented in isolation reported RVF/LH advantage for dominant meanings and LVF/RH advantage for subordinate meanings at long SOAs (e.g., Burgess and Simpson, 1988; Anaki et al., 1998). Other studies used ambiguous words within sentential context. For example, Titone (1998) showed differences between the hemispheres for peripheral feature contexts. In this study, subjects heard sentences containing homonyms (i.e., *Since it was very large in size, he easily saw the beam*) and performed a lexical decision task to visually presented targets that were semantically related to either the dominant (*laser*) or subordinate (*wood*) meanings of the ambiguous final word (*beam*). Results showed priming effects in the LVF/RH for targets representing the subordinate meaning and RVF/LH priming for targets representing the dominant meaning of ambiguous words embedded in sentences that emphasize peripheral semantic features of subordinate meanings. However, when the sentences emphasized central features of subordinate meanings, priming for targets representing either the dominant or the subordinate meanings were found in both visual fields (see also Faust and Weisper, 2000). The results of Experiment 1 are also consistent with studies with RHD patients who draw on the literal meanings of stimuli and fail to appreciate the alternative metaphorical meaning (Winner and Gardner, 1977; Van Lancker and Kempler, 1987). Thus, the findings of Experiment 1 are consistent with reports of differential semantic priming in the two hemispheres (e.g., Anaki et al., 1998; Burgess and Simpson, 1988; Chiarello, 1991; Coney and Evans, 2000), and suggest that the RH may play a privileged role in metaphor comprehension because it maintains activation of distantly related meanings (e.g., subordinate or figurative) for longer periods.

Finding a main effect of visual field which favors the LVF/RH is rather innovative. In lexical decision tasks, there is almost always a standing RVF/LH advantage. However, this somewhat unusual RH advantage might result from the relatively fast RTs for the literally related target words (Id_Lit) that were presented to the RH (see also Schmidt et al., 2007). Similar findings were obtained in another recent behavioral experiment (Faust and Mashal, 2007). In this study, participants were presented with four types of word pairs – literal, conventional metaphoric, novel metaphoric expressions, and unrelated word pairs – and were asked to perform a semantic judgment task to the second word. As in the present study, participants responded faster to target words presented to the LVF/RH than to the RVF/LH resulting from faster and more accurate responses to novel metaphoric expressions in the RH as compared to the LH. Thus, the results of these two studies indicate that during word recognition, the RH activates a broader range of related meanings than the LH, including novel, less or nonsalient salient meanings. This may lead to RH advantage in lexical decision (see also Mashal and Faust, 2007, for RH sensitivity to novel metaphoric expressions).

Additional support for the prediction that the processing of nonsalient interpretations relies on RH mechanisms was found in a lesion study (Giora et al., 2000), in an fMRI study (Eviatar and Just, 2006) and in two divided visual field experiments (Faust and Mashal, 2007; Schmidt et al., 2007). In the lesion study (Giora et al., 2000), it was found that RH brain damaged patients performed worse than LH brain damaged patients in understanding nonsalient sarcastic statements. In the divided visual field experiment of Schmidt et al., stimuli were literal and metaphorical sentences that varied in their degree of familiarity (i.e., salience). Subjects performed a semantic judgment task to the final sentence word. Results revealed RH advantage for sentences containing unfamiliar word combinations (e.g., *The close friends were a bag of toffees*), and a LH advantage for familiar sentences containing close semantic relationships (e.g., *The crooked politician told lies in every debate*), regardless of whether sentences were metaphorical or literal. The authors concluded that relatively unfamiliar sentences tend to contain coarse semantic relationships and thus, in line with the RH coarse coding model (Beeman, 1998), their findings support the role of the RH in processing nonsalient linguistic meanings.

The aim of the fMRI experiment of the present study was to identify more specifically the RH areas involved in the processing of nonsalient compared with salient meanings. The direct comparison, Id_Lit > Id_Id, elicited stronger activation in right MTG and right aSTG and the conjunction analysis (Id_Lit > Id_Id and Id_Lit > Lit_Lit), elicited activation in right precuneus, right MFG, and right MTG. However, the opposite contrast, Id_Id > Id_Lit, resulted in stronger left lateralized activation. As expected, LH activation was higher when subjects processed idioms (i.e., the idiomatic meaning of the idioms) than when they processed literal sentences (i.e., the literal interpretation of the matching literal sentences). These findings are consistent with our hypotheses and show that salient meanings, i.e., familiar, salient meanings, are processed mainly by the LH. Moreover, our results also suggest that although both tasks (processing idioms and literal sentences) involve the processing of the salient meanings of sentences, idiom comprehension relies additionally on a few left lateralized brain regions: the MTG, IFG, Thalamus, and insula.

The left IFG was found to be consistently activated during the performance of semantic tasks and, specifically, when selecting relevant features from a set of competing alternatives (Thompson-Schill et al., 1997; Gabrieli et al., 1998). Although the left Thalamus is not a cortical site, it participates in language and memory processes, since reciprocal connections exist between cortical sites and the Thalamus (Carpenter, 1985; Johnson and Ojemann, 2000; Radanovic et al., 2003). Indeed, a recent fMRI study (Stringaris et al., 2007) also provided evidence for the involvement of the left

Thalamus in deriving meaning from conventional metaphoric sentences. In this study, participants read either metaphoric (*Some surgeons are butchers*), or literal (*Some surgeons are fathers*), or meaningless sentences (*Some surgeons are shelves*) and decided whether they made sense or not. The authors suggest that the observed thalamic activation reflects semantic processing during which novel categorical associations between the words (*surgeons – butchers*) are constructed. The involvement of the left IFG and left MTG in processing the metaphoric meanings of the metaphorical sentences, as compared to processing the matching literal sentences literally, was found in another fMRI study (Rapp et al., 2004). In that study, subjects read less conventional metaphoric (*the lovers' words are harp sounds*) and literal (*the lovers' words are lies*) sentences and judged whether they had positive or negative connotations. When reading the metaphoric sentences was compared to reading the literal sentences, activation was observed in the left IFG and the left middle/inferior temporal gyri.

With regard to RH involvement in processing nonsalient meanings, the accumulated neuroimaging data point to the same right lateralized brain regions that were observed in our study. In particular, the right posterior MTG, anterior STG (aSTG), precuneus, and MFG were found to be associated with semantic activation, semantic integration, mental imagery, and selective attention, respectively. In the present study, the direct comparison Id_Lit > Id_Id elicited stronger activation in the right posterior MTG and the right aSTG. As noted by Jung-Beeman (2005) bilateral posterior superior MTG activation reflects 'semantic activation' processes whereas 'semantic integration' is mediated by anterior parts of the superior (and middle) temporal gyrus. 'Semantic activation' refers to the initial access to semantic representations, activating first-order associations of the input word. 'Semantic integration' refers to the process of attributing meaning at the sentence or story level, by computing the degree of semantic overlap among multiple semantic fields. According to Jung-Beeman (2005), meanings of individual words are processed in posterior parts of the left and right superior temporal cortex whereas comprehending sentences is associated with anterior parts of the temporal cortex. More specifically, the right posterior MTG maintains weak, diffuse semantic activation of broader semantic fields, including more distant, subordinate meanings of ambiguous linguistic expressions (Jung-Beeman, 2005). As confirmed by the pretests, the idioms that were used in the present study were ambiguous, conveying both dominant (idiomatic) and subordinate (literal) meanings. Thus, the involvement of the right posterior MTG activation might reflect the semantic activation related to the processing of the subordinate meanings of the idioms.

In line with the predictions of the GSH, it is possible that when subjects were asked to process the nonsalient meanings of the idioms, i.e., to think about their literal interpretation, they actually had to reinterpret the salient, idiomatic interpretation of the idioms. This situation may be somewhat similar to insight problem solving since "solutions to insight problems often require individuals to ignore the initially accessed interpretation of a problem element in order to access alternative interpretations" (Fiore and Schooler, 1998, p 356). According to the configuration model, literal and figurative processing of idioms run in parallel for a while until the idiomatic meaning is taken as the intended interpretation. There is considerable evidence, specifically from semantic priming (Schmidt et al., 2007; Beeman et al., 1994; Chiarello et al., 1990; Anaki et al., 1998; Drews, 1987), neuroimaging (Eviatar and Just, 2006; Mashal et al., 2005; Mashal et al., 2007; Jung-Beeman et al., 2004), and ERP (Laurent et al., 2006; Sotillo et al., 2005; Pobric et al., 2008) studies suggesting that the RH may be more likely than the LH to access alternative, nondominant meanings.

The role of the right anterior temporal lobe in sentence processing (Xu et al., 2005; Humphries et al., 2001) and 'semantic integration' (Jung-Beeman, 2005) is supported by neuroimaging studies. For example, in an fMRI study (Kircher et al., 2001), subjects read simple literal sentences ("All the guests had a good…") with several plausible endings, and were asked to generate a final word, to decide which of two presented words is more suitable as the final word of the sentence, or to read the final word. When subjects generated the final word (as opposed to reading the final word) activation was observed in the right STG. This task (as well as the decision task) requires that subjects activate and maintain some plausible terminal words. When the generation task was compared to both the reading and the decision tasks, activation was found in the right anterior temporal lobe (alongside the anterior cingulate, the precuneus, and left sided areas). Thus, this comparison might reflect the process of integrating the meanings of the final words into the sentence context.

Right anterior temporal lobe also showed increased activation when subjects read paragraphs without a title, thus having to integrate the passage to extract the theme, than when they read titled paragraphs (St. George et al., 1999). The involvement of this area in reading the untitled paragraphs reflects the integration of pieces of information in order to achieve global coherence and, as the authors claim, "the attempt to construct a unitary coherent model of a discourse" (p. 1323). Thus, integrating the nonalient meaning of an idiom may require greater effort than integrating its familiar, salient, idiomatic meaning. Neural activity also increases in right anterior temporal lobe when subjects are required to repair anomalies (such as case disagreement or word order violation) in auditory presented sentences, as compared to when they merely detect the anomalies (Meyer et al., 2000). These results might reflect greater effort for processing the context.

The precuneus is known to be involved in episodic memory retrieval and in imagery processes (Grasby et al., 1993; Tulving et al., 1994; Kosslyn, 1994; Fletcher et al., 1995, 1996). Episodic memory, which is related to general world knowledge and to the recall of personal events, is part of the declarative memory that is involved in remembering experienced events. According to Kapur et al. (1994) the right precuneus, together with right frontal regions, are important for the retrieval of information from episodic memory. Activation of this area was also found in a PET study that compared brain activation for processing novel metaphoric sentences to that of literal sentences, when subjects performed a semantic judgment task (Bottini et al., 1994). The authors noted that the involvement of the right precuneus in the processing of the metaphoric sentences might reflect conceptualizations of experiences or structuring the knowledge of the world as metaphorical associations in long term memory. This interpretation might support the claim that mental imagery is required for understanding the literal meanings of idioms. Thus, both in the present study and in Bottini et al. (1994) study, subjects were directed to process the nonsalient meanings of linguistic expressions (the metaphoric sentences in the PET study were unfamiliar to the subjects). For example, in our study, when subjects had to literally process the idiom "*kick the bucket*", they might have imagined a man actually kicking a bucket. Indeed, in a debriefing following the experiment most of our subjects reported that when they were asked to literally process the idioms, they tended to imagine a scene. A recent fMRI study (Mashal et al., 2005) also found evidence for the involvement of the right precuneus in processing nonsalient meanings of metaphoric expressions. Thus, results indicated that the right precuneus plays an important role in the main network involved in processing of novel metaphors but not in processing of conventional metaphors. Activation in the right MFG was also found to be associated with sustained attention (for a review, see Cabeza and Nyberg, 2000) and might be related to the shift between the two tasks in the present study. i.e., to think about either the literal or the idiomatic meaning of the idiom.

In sum, both behavioral and fMRI findings of the present study are consistent with the GSH (Giora, 1997, 2003; Giora et al., 2000) predictions that the RH is sensitive to nonsalient linguistic interpretations. The behavioral data show that literal interpretations of idioms are accessed faster than their idiomatic meanings only in the RH. Thus, these results give further support for the notion that RH is involved in ambiguity resolution. The fMRI data showed that processing salient meanings (the idiomatic meaning of idioms and the literal interpretations of literal sentences) involved LH regions whereas processing nonsalient meanings (the literal interpretation of idioms) was associated with increased activity in right brain regions. Specifically, for subordinate, nonsalient meanings, we observed increased activity in right precuneus, right MFG, right posterior MTG, and right anterior STG. The posterior middle temporal gyrus is responsible for semantic activation of multiple word meanings whereas the anterior part of the temporal cortex, specifically the aSTG, is involved in integrating words into a coherent message at the sentence level. It is suggested that the activation in right MFG is associated with attention and the right precuneus reflects the use of mental imagery. The processing of nonsalient meanings of idiomatic sentences thus seems to rely on unique RH mechanisms involved in semantic activation and integration of multiple word meanings. Moreover, based on accumulated evidence from divided visual field experiments and studies with brain damaged patients our results seem to support RH contribution to semantic ambiguity resolution.

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