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Thinking outside the Left Box: The role of the Right Hemisphere in Novel Metaphor Comprehension

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Through the Looking Glass by Lewis Carroll was published in 1871 as a sequel to *Alice's Adventures in Wonderland* (1865) and has remained a popular, intriguing classic. *Through the Looking Glass* features a mirror image world where linguistic rules (in addition to other rules) are frequently violated. In this sense, it is the ultimate example of linguistic creativity. Indeed, the violation of various phonological, syntactic, semantic, and pragmatic rules is a major means by which the author creates the feeling of virtual reality.

This chapter was specifically inspired by Lewis Carroll's use of semantic violations. It will focus on mainly novel metaphoric language that violates semantic rules and use this example to better understand how the rule-based linguistic system of the brain copes with such violations. I will review research suggesting that the violation of semantic rules requires the involvement of the right hemisphere (RH). I will argue that RH contribution to the comprehension of semantic violations, such as novel metaphoric expressions, extends the range of language processing available to the brain and serves as a major tool for verbal creativity. In line with this notion, the creative use of semantic violations in *Through the Looking Glass* may be regarded as some kind of neurolinguistic mirror image to the rule-based language of the dominant, expert left hemisphere (LH), enhancing the feeling of a strange, "behind the mirror" world.

The chapter proceeds as follows. After giving some examples of semantic violations from *Through the Looking Glass*, I review briefly contemporary theorizing and research on metaphor processing by the brain suggesting that at least one component of metaphor comprehension, the ability to tolerate semantic violations, is

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associated with the RH. The review focuses mainly on the comprehension of novel metaphors as an example of semantic violations that may support verbal creativity. I will argue that the processing of novel metaphoric expressions requires an ongoing, dynamic interplay between multiple brain areas in both hemispheres and will emphasize the unique contribution of the RH to novel metaphor comprehension. Thus, although it cannot be emphasized too strongly that semantic processing, including the more flexible, creative aspects of semantics, is best viewed as a whole-brain process, previous research indicates that the RH seems to contribute uniquely to specific processes underlying metaphor comprehension. In the final sections I will discuss language as a rule-based system that nevertheless allows for rule violation or semantic "emergence" (Benari, 2005) and suggest that RH unique tolerance to semantic violations is a major resource for the cognitive system (Dascal, 2002), supporting verbal creativity (for a recent meta-analytic review on RH dominance in creative thinking and verbal creativity see Mihov, Denzler, & Förster, 2010).

In *Through the Looking Glass*, Alice, having passed through the looking glass, finds herself among things and people inhabiting the looking glass world, who use the same words that she uses, but who evidently follow some strange, unconventional lexical and semantic rules (e.g., Yaguello, 1981). For example, Humpty Dumpty, one of Carroll's most enduring characters, is remembered principally for his famous definition of the meaning of a word ("When I use a word, it means just what I choose it to mean," p. 81). This definition clearly violates rules of semantic selection and combination. Thus, no wonder that Alice, arriving from the "real" world, has great difficulty in accepting it ("The question is . . . whether you can make words mean so many different things," p. 81).

In addition to this highly flexible and creative use of word meanings by Humpty Dumpty, the characters in the "through the looking glass" world use many other types of creative language. This technique serves to create a world whose logic is different from our own, thereby underlining violations of the semantic structure of words, which is precisely what makes figures of speech possible (Yaguello, 1981). Thus, for example, Carroll uses metaphors, humor, jabberwocky, word games, "portmanteau" expressions (a term coined by Humpty Dumpty, two meanings packed up into one word, p. 83), as well as poetry. The text includes many poetic stanzas and much discussion of poetry. Humpty Dumpty states that he "can explain all the poems that were ever invented – and a good many that haven't been invented just yet" (p. 82), while Alice hopes the knight's song is not too long as "she had heard a good deal of poetry that day" (p. 109). The poems include many novel metaphoric expressions, such as the following from the opening poem: "silver laughter," "moody madness," "nest of gladness," and "shadow of a sigh" (p. 1). In addition, the text includes literal expressions that are used in a novel metaphoric way (e.g., "In fact, the more head downwards I am, the more I keep inventing new things": the knight, p.108) as well as conventional metaphors that are taken literally (e.g., "The dog would lose its temper, wouldn't it? . . . then if the dog went away, its temper would remain!": the red queen, p. 119).

Metaphor Comprehension and the Right Hemisphere

From a neurolinguistic point of view, many of the above-described linguistic phenomena of the mirror image world seem to be highly associated with the unique language of the RH. Although the findings are not entirely consistent, much research indicates that the RH plays a major role in processing metaphors, connotative meanings, humor, lexical ambiguity, and insight problem solving. In general, the RH seems to be involved in those aspects of language process that are based on a highly flexible, open semantic system (e.g., Bowden & Jung-Beeman, 2003; Chiarello, 2003; Faust & Chiarello, 1998; Faust & Mashal, 2007; Fiore & Schooler, 1998; Jung Beeman et al., 2004). RH semantic flexibility and tolerance of semantic violations has been especially emphasized in connection with the processing of metaphoric expressions (e.g., Anaki, Faust, & Kravetz, 1998; Brownell, Simpson, Bihrle, Potter, & Gardner, 1990; Burgess & Chiarello, 2006; Faust & Mashal, 2007; Mashal, Faust, & Hendler, 2005; Schmidt, DeBuse, & Seger, 2007). Thus, metaphor comprehension may involve the retrieval of alternate, distantly related, and even seemingly unrelated meanings in order to integrate unusual or unfamiliar word combinations

Since metaphor comprehension appears to require semantic processing that is subserved by a distinctive neural network, the widespread use of metaphoric expressions is one of the most interesting phenomena of human language (e.g., Lakoff & Johnson, 1980). Perhaps one major reason for their abundance in language is that metaphors ("My job is a jail") permit the efficient expression of ideas that would otherwise be awkward to explain literally (Glucksberg, 2001). Figurative language thus seems especially useful in informing others about one's own attitudes and beliefs in indirect, ambiguous ways (Gibbs, 1994). In addition, metaphoric language plays a central role in reflecting, and perhaps shaping, how people think in a broad range of domains (e.g., Cacciary & Glucksberg, 1994). According to Pinker (2007), using a metaphor requires us to manipulate ideas in a deeper stratum of thought, thus our conceptual system is fundamentally metaphorical. Furthermore, metaphors, both newly invented and conventional, are widely used in poetry, where with a few words, implicit and explicit emotions and associations from one context can powerfully be associated with another, different context. Indeed, Aristotle wrote in his *Poetics* that "the greatest thing by far is to be a master of metaphor."

A metaphor has been traditionally defined as a denotative violation since it conveys information by describing a thing in terms of what it is not (Billow, 1975). Metaphors are often characterized as involving two seemingly unlike things compared, as opposed to literal comparisons involving two things that are clearly alike (Cacciary & Glucksberg, 1994). According to Beck (1987), the understanding of metaphors (such as "This idea is a gem") "forces the mind" to construct a high-order mental linkage of two different, frequently unrelated, category domains, the "topic" or "target" of the metaphor ("idea") and the "vehicle" or "base" of the metaphor ("gem"). This "bridging" effort is required because the idea is not really a gem but rather it shares some properties with a gem (preciousness, uniqueness, but not the color of the gem). Richards (1936) refers to the shared properties between the topic and the vehicle of the metaphor as the "ground" of the metaphor. Thus "understanding a metaphor can be seen as the process by which the metaphor's ground becomes available and salient" (Pynte, Besson, Robichon, & Poli, 1996, p. 294).

Although metaphoric expressions may involve the use of both previously acquired and newly created categories and conceptual linkages (Cacciary & Glucksberg, 1994), the relation between the vehicle and the topic of a metaphor, either conventional or novel, can be characterized as relatively unusual and distant. Metaphoric, as opposed to literal, language comprehension involves some kind of meaning extension through the establishment of correspondence between concepts from disparate knowledge domains (for a review, see Bowdle & Gentner, 2005). Several different models have been postulated to explain the mechanisms that deal with the literal/metaphoric duality (e.g., Glucksberg, 2003; Grice, 1975), focusing mainly on conventional, frequently used, metaphors. Thus, for example, research on the precedence of meaning access (e.g., the claim that figurative and literal meaning is accessed concurrently) is based largely on studies of conventional metaphors (for reviews, see Giora, 2002; Glucksberg, 2001, 2003).

The distinctive nature of the comprehension of unfamiliar or novel metaphors, such as those used in poetry and other creative texts, has been, for the most part, overlooked, in spite of findings suggesting that novel metaphors are processed differently than conventional ones (e.g., Ahrens et al., 2007; Amanzio, Geminiani, Leotta, & Cappa, 2007). Ahrens et al. (2007) conclude, on the basis of their functional magnetic resonance imaging (fMRI) study of the processing of conventional and novel, anomalous metaphoric sentences, that conventional and novel metaphors can no longer be grouped together. Instead, they suggest that in order to make further discoveries on semantic processing, finer-grained distinctions should be used to categorize metaphors into different semantic groups. Similarly, Amanzio et al. (2007), who tested metaphor comprehension in Alzheimer patients and healthy control subjects, concluded that different brain mechanisms are involved in processing conventional and novel metaphors.

The findings of several studies to date, including those from our lab, also suggest that although both conventional and novel metaphors involve some kind of semantic violation, they are different semantic categories involving different semantic and neural processing mechanisms. However, only a few models have proposed distinct operations for novel and conventional metaphors. The career-of-metaphor hypothesis by Bowdle and Gentner (2005) posits different processing of novel and conventional metaphors. According to Gentner's structural-mapping theory (1983), metaphors are comprehended by establishing correspondences between partially isomorphic conceptual structures of the target and base. This comparison process is elicited when comprehending novel metaphors. However, as metaphors get conventionalized they become associated with a metaphoric category and may be processed using categorization as well. Categorization is more rapid and less computationally costly than comparison but requires an existing metaphoric category. When a novel metaphor is encountered, an initial categorization attempt fails due to the lack of a well-defined category. Novel metaphors are thus processed sequentially, and the comparison process begins after determining that the literal meaning cannot be sensibly applied. Furthermore, Gentner and colleagues have suggested that as novel metaphors become increasingly conventional through frequent use, there is an accompanying shift in the mode of processing from comparison to categorization (Gentner & Bowdle, 2001; Gentner & Wolff, 1997).

An additional model that has also implications for the different neural mechanisms involved in conventional and novel metaphor comprehension is the graded salience hypothesis (GSH; Giora, 1997, 2002, 2003). According to this model, the factor determining precedence of meaning access is salience and thus the interpretation of literal and metaphoric expressions is determined by their degree of saliency. The salient meaning, either figurative or literal, is the one always processed first. The figurative meaning in conventional metaphors is commonly more salient than the literal one, thus in most "dead" metaphors the figurative meaning is accessed first. In contrast, when a novel or unfamiliar metaphor is encountered, the salient meaning is the literal one, and the figurative meaning is inferred later by contextual mechanisms. The GSH posits that whereas for conventional metaphors, the salient metaphoric meaning is coded in the mental lexicon, the meaning of novel metaphors must be constructed online. Although the structural-mapping theory does not include neurolinguistic implications, the GSH predicts a selective RH involvement in the comprehension of novel, nonsalient, metaphorical meanings and LH involvement in the comprehension of conventional, salient, metaphorical meanings (Giora, 2002; 2003). This model replaces the LH/literal meaning versus RH/metaphoric meaning dichotomy by a LH/salient meaning versus RH/nonsalient meaning dichotomy.

A third model that may be applied to the hemispheric differences in the comprehension of conventional versus novel metaphors is the fine–coarse semantic coding theory (FCT; Beeman, 1998, Jung-Beeman, 2005; see also Mirous & Beeman, Volume 1, Chapter 16). This model provides an explanation of the role of the RH in metaphor processing. According to this model, the involvement of the RH in the processing of metaphors, and, specifically, in processing novel, unfamiliar metaphoric expressions may not be particular to metaphors, but rather may be one aspect of the unique semantic coding of the RH, characterized by high sensitivity to distant semantic relations. The FCT postulates that immediately after encountering a word, the LH engages in relatively fine semantic coding, strongly focusing on a few closely related word meanings or semantic features, whereas the RH engages in coarse semantic coding, weakly and diffusely activating large semantic fields containing multiple alternative meanings and more distant associates. The larger and less discriminate the semantic field, the more likely it is to overlap with semantic fields activated by other input words, including metaphorically related words.

The metaphorical meaning of a word is usually more semantically distant than its literal meaning. Consequently, the processing of a metaphoric expression may depend on the ability to activate a broader, more flexible set of semantic associations in order to integrate the meanings of the weakly related words into a meaningful linguistic expression. Furthermore, the comprehension of novel metaphoric expressions, such as those taken from poetry, may rely even more on the ability to link several distant associates in order to combine the meanings of seemingly unrelated individual words. The FCT predicts that the RH will benefit more from the unfamiliar semantic relationship between the meanings of single words appearing in a novel metaphoric expression whereas the LH may show an advantage when comprehension depends on the ability to process a highly familiar, either literal or conventional metaphoric, semantic relationship.

This distinction between conventional metaphoric and novel metaphoric expressions with regard to the differential processing by the LH and RH, respectively, is also consistent with the GSH (Giora, 1997, 2002). The integration of the FCT and the GSH could thus imply that a few salient strongly associated meanings, be they literal or metaphoric, are quickly activated in the LH. However, according to the latter integrated account of meaning processing, the RH activates and maintains multiple nonsalient weakly associated meanings, either literal or metaphoric. Both the FCT and the GSH thus predict a LH advantage for processing familiar literal and conventional metaphoric expressions and a RH advantage for processing novel, unfamiliar metaphoric expressions.

Much empirical evidence on metaphor processing by the two cerebral hemispheres is consistent with the GSH and FCT models presented above. The results of semantic priming studies as well as data collected from brain-damaged patients generally suggest that the RH contributes uniquely to the comprehension of metaphoric language. Furthermore, the extent of RH involvement in metaphor comprehension reported in previous studies may be attributed, at least partly, to differences in the linguistic and neural mechanisms involved in processing conventional and novel metaphoric meanings. The findings of several studies support this claim by showing increased RH involvement for novel (e.g., Bottini et al., 1994; Faust & Mashal, 2007; Schmidt et al., 2007) or less familiar (Anaki et al., 1998) metaphoric expressions.

The notion that metaphor, mainly novel metaphor, comprehension involves RH neurolinguistic mechanisms that can cope with semantic violations is what motivated a series of experiments conducted in our lab. This research project was based on the assumption that the processing of literal, conventional metaphoric, and novel metaphoric expressions can be dissociated experimentally and that the processing differences should manifest themselves in the pattern of hemispheric involvement and interaction during comprehension.

To date there have been very few studies that have employed behavioral mehtods, brain imaging, evoked response potentials (ERPs), or transcranial magnetic stimulation (TMS) as a means of exploring RH involvement in conventional versus novel metaphor comprehension. Furthermore, there are almost no data on individual differences in the pattern of hemispheric involvement and interaction during novel metaphor comprehension. Our research project was based on the assumption that novel, but not conventional, metaphors require the online establishment of "mental linkage" between words normally not related, posing an increased load on the semantic system. Since, according to both theoretical accounts (Beeman, 1998; Giora, 1997, 2003; Jung-Beeman, 2005) and previous research (e.g., Anaki et al., 1998; Bottini et al., 1994; Chiarello, 1998, 2003; Faust & Lavidor, 2003; Schmidt et al., 2007), the RH contributes uniquely to the activation and integration of distant, unusual and nonsalient semantic relations, our main hypothesis was that the comprehension of novel metaphoric two-word expressions taken from poetry will show a distinct pattern of neural processing. Specifically, we predicted that compared to the comprehension of both literal and highly conventional metaphoric expressions, the comprehension of novel metaphors will require unique involvement of RH mechanisms.

The Conventional Versus Novel Metaphor Brain Processing Research Project

As described above, metaphoric expressions may vary in familiarity, with novel metaphoric expressions representing the less familiar end of the familiarity continuum. Furthermore, the extent of RH involvement in metaphor processing may depend on the cognitive processes underlying familiar, conventional versus unfamiliar, novel metaphor comprehension. Based on the suggested processing difference between conventional and novel metaphors (Bowdle & Gentner, 2005; Giora, 1997, 2002) as well as on the suggested role of the RH in processing unusual semantic relations (Beeman, 1998; Jung-Beeman, 2005; Giora, 1997, 2002), we conducted a programmatic series of experiments using convergent, complementary experimental methods. In all of the experiments we used the same, simplest form of metaphoric stimuli, i.e., two-word expressions, in order to avoid the confounding effects of sentence-level processes or larger context (see, e.g., Faust, 1998; Faust, Barak, & Chiarello, 2006; Faust, Bar-Lev, & Chiarello, 2003; Peleg & Eviatar, Volume 1, Chapter 4). Furthermore, the novel metaphorical expressions were taken from original Hebrew poetry and thus had high ecological validity and were, at least potentially, meaningful. In all of the experiments, participants were presented with four types of two-word noun–noun or adjective–noun combinations, literal (e.g., "personal confession," "problem resolution," "broken glass"), conventional metaphoric (e.g., "transparent intention," "sweet dream," "lucid mind") and novel metaphoric (e.g., "wilting hope," "ripe dream," "mercy blanket") expressions as well as unrelated word pairs (e.g., "salty rescue," "indirect blanket," "drum outlet"). However, because of Hebrew grammar, the order of words in the translated examples was actually reversed. The different types of word pairs were subjected to extensive pretesting (e.g., meaningfulness, metaphoricity) and carefully controlled for all relevant parameters (e.g., frequency, concreteness, familiarity, syntactic structure; for a detailed description of the linguistic stimuli, see Faust & Mashal, 2007). The experimental task was semantic judgment.

In several behavioral experiments (Faust & Mashal, 2007; Mashal & Faust, 2008; Zeev-Wolf & Faust, 2010), the split visual field paradigm combined with priming was used. In two experiments that were identical in every other respect, we tested the processing of the four types of linguistic expressions by the two cerebral hemispheres across two different time intervals between the two words of the linguistic expressions (stimulus onset asynchronies [SOAs] of 400 ms and 1100 ms). Based on the predictions of the FCT and the GSH as well as on previous research findings on differential patterns of semantic processing by the two cerebral hemispheres, the main hypothesis of both experiments was that the RH will be faster and more accurate than the LH in performing a semantic judgment ("related/unrelated") task for novel metaphoric, but not for either literal or conventional, metaphoric expressions. This left visual field/RH advantage was expected to be more pronounced for the long SOA condition because strategic and post-access prime processing and inhibition were expected mainly to occur within the LH (for reviews, see Chiarello, 2003; Faust & Kahana, 2002)

In the two experiments, participants were presented with the four types of two-word combinations described above and asked to perform a semantic judgment task. The first word of each expression was presented centrally, followed by a focusing signal. The second, target, word was randomly lateralized to the right or left visual field. Participants were instructed to push one of two buttons; "related" if the prime and the target were semantically related and thus constituted a meaningful expression, either literal or metaphoric, or "unrelated" if the two words were not semantically related.

The findings of the two experiments were very similar and generally confirmed the main hypothesis. A RH advantage was found for both accuracy and reaction time (RT), indicating that the novel metaphors were comprehended better and faster when initially presented to the RH. However, as expected, for either literal or conventional metaphors, no RH advantage was found. The putative effect of SOA on the pattern of responding to the different linguistic stimuli was not found. A recent experiment that replicated the behavioral split visual studies used two different SOAs of 150 and 650 ms (Zeev-Wolf & Faust, in preparation). Here too, a left visual field/ RH advantage was expected only for the long SOA condition. The findings confirmed the hypothesis showing a similar pattern of processing for both hemispheres in the short SOA but RH superiority for novel metaphors in the long SOA. The findings are also consistent with the FCT and suggest that distant meanings are initially activated in both hemispheres but maintained only in the RH for further integration.

Although the findings of the three experiments did not show a RH advantage for the other type of unfamiliar expression (i.e., unrelated word pairs), a subsequent split visual study (Mashal & Faust, 2008) was designed to determine whether RH superiority for novel metaphor comprehension reflects genuine sensitivity to distant semantic relations or just a more liberal semantic criterion applied for all unfamiliar expressions, either meaningful or meaningless. We thus used the signal detection paradigm that allows for the separation of sensitivity (d') from response bias ($\boldsymbol{\beta}$, response criterion), and computes estimates of each. In each of the two experiments, participants were presented with two types of expressions, half of which were meaningful (either novel or conventional metaphors in the two experiments, respectively) and half, meaningless (unrelated word pairs) and asked to perform a semantic judgment task. The signal detection data analyses provided an estimation (d') of how easy it is to separate "signal" (i.e., either novel metaphors or literal expressions) from "noise" (i.e., unrelated word pairs). The results replicated those of the previous split visual field experiments, showing RH advantage only for the novel metaphors but not for the literal expressions. No hemispheric differences were found for β. Furthermore, the findings showed higher sensitivity (d') for novel metaphors initially presented to the RH as compared to those presented to the LH, indicating a higher ability of the RH to differentiate between novel metaphors and unrelated word pairs. These findings support a unique sensitivity of the RH to distant, unusual semantic relations that is nevertheless highly selective and does not extend to all unfamiliar combinations. The literal pairs, based on familiar, rule-based semantic relationship, showed a significant LH advantage in response criterion.

RH advantage for novel metaphor comprehension was replicated in yet another study (Mashal & Faust, 2009) that was motivated by the above mentioned models postulating different mechanisms for the comprehension of conventional as opposed to novel metaphors (Bowdle & Gentner, 2005; Giora, 1997, 2002, 2003). According to the career-of-metaphor model (e.g., Bowdle & Gentner, 2005), the process of conventionalizing novel metaphors is accompanied by a processing shift from comparison to categorization. Although, as pointed out above, Bowdle and Gentner do not spell out the neurolinguistic implications of their model, this shift could be interpreted neurolinguistically as a shift from LH to RH processing. However, such changes in brain processing as a result of the conventionalization of novel metaphors do not appear to have been tested before.

Using the divided visual field technique, we tested the possibility that the conventionalization of novel metaphors will be accompanied by a shift from RH to LH processing. Participants were presented with novel and conventional metaphoric expressions, literal expressions, and unrelated word pairs and completed the same experiment twice. Following the first experiment, half of the participants were explicitly directed to think about the meanings of the four types of linguistic stimuli. Then the second experiment, which was identical to the first, was carried out by all of the research participants. The results showed hemispheric changes from a RH advantage during initial exposure to similar hemispheric performance as a result of the conventionalization of novel metaphoric expressions only on the part of those participants who had been asked to elaborate the meaning of all of the linguistic stimuli. During the first and second experiments, for all of the research participants, the other types of linguistic expressions did not show a shift in hemispheric advantage.

While the series of the above behavioral experiments supported the notion of RH selective sensitivity to novel, unusual semantic relations, the aim of another study that used the same stimuli was to directly identify the specific RH brain areas involved in novel metaphor comprehension. In this study (Mashal et al., 2005;

Mashal, Faust, Hendler, & Jung-Beeman, 2007), we used a common brain imaging technique, fMRI, to test the claim that the RH has a primary role in processing novel metaphoric expressions. This technique enables localization of brain function by monitoring the hemodynamic changes associated with neural activity. Participants were presented with the four types of two-word expressions used in the above-described experiments and asked to decide whether each expression was meaningful or meaningless. The results showed that when compared with conventional metaphors, there were significant regions of activation for novel metaphors in the right posterior superior temporal gyrus (PSTG), the homologue of Wernicke's area. In addition, significant greater percent signal change for novel metaphors than for both literal expressions and unrelated word pairs was also found in the right PSTG. Stronger activation in the right PSTG for the novel metaphoric expressions than for either literal or conventional metaphoric expressions points to the special role of this brain region in the construction of novel semantic connections.

The fMRI findings were further subjected to principal component analysis (PCA) to analyze brain functioning in terms of networks. The functional connectivity principle points to the interactions and the integration that link the dynamics of specialized regions (Friston, 1998). This principle is based on the assumption that each experimental condition, i.e., each cognitive or linguistic process, may be mediated by a different functional network. Thus, if a specific brain region belongs to the same functional network (i.e., component in terms of PCA) as other regions in one condition but to a different component in another condition, this means that this area interacts differently with other brain areas in each condition and thus might play a different role in processing the various linguistic stimuli.

The PCA analysis identified a special, unique network recruited for the processing of the novel metaphoric expressions, obtained from the second component of the novel metaphor condition. Thus, when processing unfamiliar yet potentially meaningful linguistic expressions, activation in the right homologue of Wernicke's area was highly correlated with activation in frontal areas: Broca's area, left and right insula, and left and right premotor areas.

The causal role played by the right PSTG in the processing of novel metaphoric expressions was further established in two repetitive transcranial magnetic stimulation (rTMS) experiments (Pobric, Mashal, Faust, & Lavidor, 2008). Thus, the causal role of a specific brain region can be estimated by measuring the magnitude of impairment resulting from applying magnetic stimulation to that specific region. In both experiments, participants were presented with English translations of the four types of two-word expressions used in the previously described experiments and asked to perform a semantic judgment task. The findings of the two experiments were very similar and showed that rTMS over the right homologue of Wernicke's area (more precisely over the right posterior superior temporal sulcus, PSTS), that has been previously identified as the critical RH area involved in novel metaphor processing (Mashal et al., 2005, 2007), disrupted processing of novel but not conventional metaphors. However, rTMS over the left inferior frontal gyrus

(IFG) selectively impaired processing of literal word pairs and conventional but not novel metaphors.

In the second experiment, using rTMS over additional brain areas, these findings were replicated (Pobric et al., 2008). Thus, the TMS data analysis revealed that TMS over the right PSTS caused a significant inhibition for novel metaphors, i.e., slowed down the processing of novel metaphoric expressions. However, an additional, unexpected finding was that TMS over the left PSTS caused facilitation in responses to novel metaphors, i.e., enhanced novel metaphor comprehension. Significant interference TMS effects were created for conventional metaphoric and literal expressions when TMS was applied over the left and right IFG, respectively, in comparison to the control condition. This study was the first demonstration of TMS-induced impairment in processing novel metaphoric expressions, and as such confirmed the specialization of the RH in the activation of a broader range of related meanings than the LH, including novel, nonsalient meanings. In addition, the pattern of results strongly indicates that RH involvement in semantic processing is highly selective and limited to novel metaphors, i.e., it does not extend to either conventional metaphors or other unfamiliar nonmetaphoric expressions (unrelated word pairs).

Furthermore, the unexpected finding of the second experiment, showing an opposite pattern of facilitation in processing novel metaphors following TMS over the left PSTS may suggest that interfering with LH activity may facilitate novel metaphor comprehension in the RH. Since previous studies have shown that TMS of one region may disinhibit the homologous regions in the contralateral hemisphere (Seyal, Ro, & Rafal, 1995), such a disinhibition mechanism may have operated in this study. TMS over the left PSTS may have caused the disinhibition of the right PSTS, leading to faster RTs as compared to the control condition**.** According to this explanation, LH inhibitory semantic processing mechanisms may interfere with RH ability to integrate the individual meanings of two seemingly unrelated concepts into a meaningful metaphoric expression.

To add a temporal dimension to hemispheric asymmetries during metaphor comprehension, we used ERPs. This technique provides measures of brain activity with very high temporal resolution. When coupled with methods for source localization, it can provide an estimation of the neural sources involved (Arzouan, Goldstein, & Faust, 2007a, 2007b; Goldstein, Arzouan, & Faust, 2008). Different processes are reflected as different ERP components, whereas variations in effort or difficulty are manifested as amplitude or latency differences in a specific component. ERP measures can thus assist in pinpointing the processing stages at which metaphorical meaning is achieved. These techniques were applied in several experiments to study the timeline of hemispheric dynamics during the processing of conventional and novel metaphoric two-word expressions

The few studies that have investigated metaphor comprehension using ERPs (e.g., Bonnaud et al., 2002; Coulson & van Petten, 2002; Iakimova et al., 2005; Pynte et al., 1996; for a review, see Arzouan et al., 2007b, and Coulson & Davenport, Volume 1, Chapter 19) focused on a particular ERP component, the N400, which is a negative deflection peaking approximately 400 ms after stimulus presentation. The amplitude of the N400 has been shown to vary systematically with the processing of semantic information and can be thought of as a general index of the ease or difficulty of retrieving stored conceptual knowledge associated with a word (e.g., Kutas & Federmeier, 2000; see also Kutas, Kiang, & Sweeney, Volume 2, Chapter 26). Regarding processing stages later than the retrieval of the semantic information of words, findings in the literature are less consistent. The late positive component (LPC) or P600 usually appears following the N400 and has been thought to reflect sentence-level integration (Kaan et al., 2000) or reanalysis (Friederici, 1995) and memory retrieval processes (Paller & Kutas, 1992; Rugg et al., 1995).

In several ERP experiments (Arzouan et al., 2007a, 2007b), we measured the electrical brain response of participants to the literal, conventional metaphoric, novel metaphoric, and unrelated expressions. The two-word expressions were presented centrally in a random order, one word at a time, each for 200 ms with an interval of 200 ms between words. Participants were instructed to "judge whether the presented two-word expression conveys a meaning (be it literal or metaphoric) or does not convey a meaning as a pair," and press a corresponding key. ERPs to the second word of the expression were derived and entered into a neural-source estimation algorithm (LORETA), and current density at each brain area was compared between expression types.

The findings of the ERP experiments (Arzouan et al., 2007a) showed the N400 amplitude gradient. This gradient started with small N400 for literal relations and increased for conventional metaphors and novel metaphors. Finally, it was largest for unrelated words. Thus, while retrieving the stored conceptual knowledge associated with novel metaphors was more demanding than retrieving knowledge of conventional metaphors or literally related words, meaning was accessed, at least initially, in a similar manner. In addition, the ERP results indicated that the dynamics of hemispheric activity are complex and vary across processing stages and brain areas (Arzouan et al, 2007b; Goldstein et al., 2008). The processing mechanisms used for all types of expressions were similar, as indicated by similar elicited components and parallel fluctuations in brain volume activation. Both hemispheres were active during the comprehension of all expressions as reflected in the absolute current density values and number of active voxels in each hemisphere. However, the relative contribution of each hemisphere at specific processing stages depended on stimulus type. These stages correspond roughly to the N400 and LPC components that reflect semantic and contextual integration. Both the brain volume activity and the current density analyses yielded converging evidence of relative asymmetric processing, increased processing for RH areas relative to LH areas only during novel metaphor comprehension. This asymmetry appears to stem from activity in right temporal and right superior frontal areas. The temporal regions include the right homologue of Wernicke's and surrounding areas. Relative asymmetry toward LH areas was found for all other types of linguistic expressions.

These results are in agreement with those of the imaging studies that have distinguished novel from conventional metaphors. It appears that novel metaphoric expressions activate RH temporal areas more than conventional metaphors or literal expressions. The advantage of ERP data is that it facilitated the identification of the processing stage at which such hemispheric asymmetries occur. The findings for the N400 component also suggest that understanding novel metaphors requires the retrieval of more semantic information about the words in order to bridge the gap between seemingly unrelated words. This claim is supported by the findings of a recent ERP study (Goldstein, Arzouan, & Faust, in preparation) suggesting that the conventionalization of novel metaphoric expressions reduces the semantic integration effort invested by the brain during attempts to comprehend these expressions.

An additional approach to examine changes in hemispheric activity over time is to use statistical nonparametric mapping (SnPM; Nichols & Holmes, 2002). According to this technique, for each condition and on each time point, current density was compared. The findings of our ERP study (Arzouan et al., 2007b) showed that the fluctuations in the number of supra-threshold voxels were mostly parallel in both hemispheres. Nevertheless, asymmetries occurred during various periods. Novel metaphoric expressions elicited more relative RH activity (as reflected by the number of supra-threshold voxels) at two time windows, 350–450 ms and 550–750 ms approximately, with three prominent peaks at about 425, 600 and 710 ms. At those same time windows (and throughout most of the epoch), conventional metaphors showed relative greater LH activity. LT and unrelated expressions elicited more relative LH activity mainly at the first time window. Although this approach estimates the bulk activity of each hemisphere, it does assist in giving a general picture of the dynamics of hemispheric interactions. Thus, the findings suggested that although both hemispheres were active during the comprehension process of all expressions, there are relative LH and RH asymmetries at specific stages as reflected in the absolute current density values and the number of active voxels in each hemisphere.

Initial findings of high activation of RH temporal areas for novel metaphor processing during specific points in time are also found in a pilot study (Zeev-Wolf, Goldstein, & Faust, 2010) using the magnetoencephalography (MEG), an imaging technique used to measure the magnetic fields produced by electrical activity in the brain via extremely sensitive devices (SQUIDs). The MEG technique thus offers both high spatial and high temporal resolution in brain imaging. Findings of this MEG study that used the same paradigm and stimuli as those used in the ERP studies showed a similar grading of the M350, the magnetic counterpart of N400, for the four types of stimuli. Furthermore, during this point in time higher activation was found in RH temporal areas, homologue to Wernicke's area, for novel metaphors, whereas for literal expressions and conventional metaphors we found higher activation in Wernicke's area. Higher activation in RH temporal areas for novel metaphors was also found when these expressions were compared with unrelated word pairs.

Individual Differences in Novel Metaphor Comprehension in the RH

The unique contribution of RH areas to the processing of novel metaphoric expressions has been repeatedly shown in several studies using convergent experimental methods. However, the findings of two additional studies suggest that there may be marked individual differences in the extent of RH involvement. Furthermore, the findings of these studies suggest that individual differences in the extent of RH involvement in metaphor comprehension are related to verbal creativity and to the ability to tolerate semantic violations.

In a recent divided visual field study (Gold, Faust, & Ben-Artzi, in press), we tested the hypotheses that novel metaphor comprehension is a process of linguistic creativity that seems to rely on RH coarse semantic coding mechanisms (e.g., Faust & Mashal, 2007). This study focused on the relation between linguistic creativity as measured by an offline standard test of verbal creativity and RTs for correct identification of novel metaphors, conventional metaphors, literal, and unrelated word pairs in a group of healthy adults. Linguistic creativity was measured by performance of the Hebrew version of the Mednick Remote Association Test (RAT; Mednick, 1962), based on triads of words each of which is remotely related to a single solution word.

Participants were asked to perform the Hebrew version of the RAT and we tested the relation between linguistic creativity as measured by performance on this test and RTs for correct responses to the four types of expressions. Results indicated that performance on the RAT, as measured by scores on the Hebrew version of this test, was significantly correlated with RTs to novel metaphors only when the metaphors were presented to the left visual field/ RH. In addition, verbal creativity scores were significantly correlated with RT to conventional metaphors in both the LH and the RH. There was no correlation with performance on either the literal or the unrelated word pairs. These results were interpreted as suggesting that the RH contribution to novel metaphor comprehension may be related to the critical involvement of the intact RH in verbal creativity (Bowden & Beeman, 2003). Thus, highly verbally creative persons show higher RH involvement when processing the meanings of the two distantly related words comprising the novel metaphoric expressions. The RAT contains many words that are related to the solution word via conventional metaphoric relations. Therefore, performance on this test and semantic judgment for conventional metaphors were closely related when the semantic task was performed by both hemispheres.

To further study individual differences in the extent of RH involvement in novel metaphor comprehension, we applied the split visual field paradigm to the study of metaphor comprehension in persons with Asperger syndrome (AS; Gold & Faust, 2010). AS is a neurodevelopmental disorder on the autistic spectrum (autistic spectrum disorder – ASD) characterized by social impairments, difficulties in communication, and a set of circumscribed interests and/or a rigid adherence to routines (e.g., Lombardo, Barnes, Wheelwright, & Baron-Cohen, 2007). Although there is no significant delay in language or cognitive development (APA, 1994), persons with AS often exhibit difficulties in comprehending specific linguistic forms, mainly nonliteral language and metaphors (MacKay & Shaw, 2004).

According to Baron-Cohen's model of systemizing versus empathizing in ASD (e.g., Baron-Cohen, 2003), the relative degree of systemizing versus empathizing tendencies can explain behavioral and cognitive characteristics of the general population and of ASD. Since systemizing refers to the inclination to analyze systems and to understand and predict behavior in terms of underlying rules, we assumed that this tendency can be generalized to language processing as well and that different kinds of linguistic stimuli may vary in the degree of systemizing involved in their efficient processing. Thus, the tendency to systemize may interfere with the comprehension of novel metaphoric expressions that involve semantic rule violations.

The study examined the relative contribution of the RH and LH in AS to metaphor comprehension. It was based on previous research suggesting that AS is a specific neuropsychological disorder associated with RH dysfunction and can be understood by analogy to RH damage, developmental disabilities involving RH dysfunction, and nonverbal learning disabilities (e.g., Ellis, Ellis, Fraser, & Deb, 1994). The study's main hypothesis was that RH dysfunction in persons with AS may account for their observed difficulties in metaphor, mainly novel metaphor, comprehension. Specifically, we expected a reduced RH advantage for novel metaphor comprehension in the AS group as compared to a control group of healthy participants.

The findings of this study generally confirmed the hypothesis. Although the control group of healthy participants demonstrated the expected RH advantage for novel metaphor comprehension, AS persons with normal or above normal levels of language ability showed no RH advantage for the comprehension of these stimuli (Gold & Faust, 2010). These findings support the claim that the RH in AS participants may be less efficiently involved in the process of novel metaphor comprehension. Interestingly, the results pointed to a marginally significant tendency towards LH superiority for the comprehension of novel metaphors by the AS participants.

The difficulty that persons with AS experience with the semantic integration required for the processing of novel metaphoric expressions was demonstrated in another study (Gold, Goldstein, & Faust, 2010) that used the ERP method for studying semantic processing of the four types of linguistic stimuli. For persons with AS, N400 amplitudes for novel metaphor comprehension were larger and not different than those for unrelated word pairs. However, for the control group, the N400 amplitudes for novel metaphors were smaller than those for unrelated word pairs.

The findings of the latter studies (Gold et al., in press; Gold & Faust, 2010; Gold et al., 2010) point to a systemizing–nonsystemizing continuum that can serve as a theoretical framework for understanding language processing in the intact brain as well as in various clinical populations. This continuum emphasizes the relative involvement of the two intact cerebral hemispheres depending on degree of systemizing versus nonsystemizing required for processing specific linguistic expressions.

In line with an above-cited study, Gold et al. (in press) showed that the extent of RH involvement in novel metaphor comprehension is highly related to verbal creativity. Accordingly, the idea of a dysfunctional RH in AS can also be extended to account for aspects of language functioning related to linguistic creativity. Thus, the link between difficulties in comprehending novel metaphoric expressions and RH dysfunction may have some wider implications for linguistic creativity in persons with AS. According to this claim, novel metaphoric expressions represent a unique and original combination of two seemingly unrelated concepts (e.g., "ripe dream," "gem eyes"). The ability to semantically relate two concepts, despite the fact that they are not usually linked together and are not coded in the mental lexicon, may require a creative linguistic process in order to establish novel, original semantic relations. This is in contrast to rule-based language processing such as syntax or literal semantic comprehension that may rely on pre-stored information. As mentioned above, creative thinking has previously been related to the RH (Beeman et al., 2004; Faust & Kahana, 2002), and it has been hypothesized that this process may profit from the coarse semantic coding attributed to the RH (Beeman et al., 2004). This notion is consistent with previously reported deficient creative thinking abilities in AS (Craig & Baron-Cohen, 1999). Thus, the difficulties in novel metaphor comprehension experienced by persons with AS may be one aspect of a more general underlying deficit in linguistic creativity related to RH dysfunction. Nevertheless, in accordance with Baron-Cohen's model, the more rule-based aspects of language are usually spared in persons with AS.

Metaphor, Rule Violation, and Emergence: The Contribution of the RH to Semantic Creativity

In this chapter, I offered an interpretation of the differences in semantic processing carried-out by the two cerebral hemispheres. This interpretation was based on a series of studies that used convergent experimental methods and investigated the role of the RH in processing conventional and novel metaphoric two-word expressions. The findings of this series of studies indicate that understanding novel metaphoric two-word expressions taken from poetry involves specific areas of the temporal lobe of the RH that are homologues to Wernicke's area. Furthermore, the ERP and MEG data suggest that RH involvement is manifested during specific points in time associated with semantic retrieval and integration. Such RH involvement was not found for conventional metaphors, literal expressions, or unrelated, meaningless expressions. For these linguistic stimuli, we generally found strong LH involvement. However, the TMS data suggest that LH linguistic mechanisms may interfere with novel metaphor comprehension.

Our research has also demonstrated that there are marked individual differences in the extent of RH involvement in novel metaphor comprehension. Thus, persons who score high on the RAT verbal creativity test, based on unusual word combinations, show higher RH involvement in novel metaphor comprehension. However, persons with AS, who tend to have specific difficulties with linguistic stimuli that are less systemized, i.e., that involve some degree of rule violation, show less RH involvement. Based on the findings of our research, I suggest that hemispheric differences are associated with individual differences in the comprehension of metaphoric word combinations. In turn, this association may be related to the LH rule-based versus the RH emergent, rule-violating semantic processing.

According to this claim, the meaning of a literal or a conventional metaphoric expression can usually be predicted on the basis of a full, systematic and comprehensive description of the semantic relations between the individual words comprising it. Thus, the comprehension of literal expressions is usually based on the processing of semantic relations between interconnected words in the semantic network. Similarly, the comprehension of most conventional, frequently used metaphoric combinations is also based on the retrieval of pre-established, salient semantic relations (e.g., Bowdle & Gentner, 2005; Giora, 2003). The systematic, constraining semantic relation may thus offer a processing advantage for the rule-based semantic system of the LH.

However, when the semantic relations between the two words comprising a linguistic expression are distant and unusual, such as in novel metaphors, the rule-based semantic system of the LH may require a complementary neural system that is able to cope with the potential rule violation created by nonconventional semantic combinations. The comprehension of novel semantic combinations may thus be characterized by "emergence." "Emergence" is used here to refer to a process whose final outcome cannot be fully predicted on the basis of the individual components of the linguistic expression (Benari, 2005). The distant, unusual semantic relations between the two words comprising a novel metaphoric expression may thus require an open and flexible semantic system that is able to tolerate semantic violations and cope with multiple, including less predictable, interpretations. According to the fine–coarse semantic coding hypothesis (Beeman, 1998; Jung-Beeman, 2005), broader semantic fields of the RH may be better able to capture certain types of semantic relations, those that depend on the overlap of distantly related meanings.

Furthermore, such a semantic system may be highly advantageous for cognitive and linguistic processing. Dascal (2002), in his review of language as a cognitive tool, argues that the rule-based linguistic system is constrained and limited in its ability to express the more subtle aspects of communication, i.e., the spirit and the mind and not only the thought. It is for such purposes that the rule-based linguistic system must be complemented by a different system that can compensate for the former system's "mechanical" limitations. Furthermore, Dascal suggests that a particularly significant feature of the linguistic system is that it sometimes achieves its aims by resorting to explicit violations of the system's rules, such as in metaphor, puns, and nonsense poetry. From a cognitive point of view, a rule-based system that uses different kinds of rules and, in addition, permits and even exploits the violation of its own rules is extremely valuable. Such a system does not always treat rule violations as mistakes and thus may support many important cognitive processes that are open-ended, flexible, and creative. Dascal suggests that a successful metaphor created in order to understand a new concept (i.e., a novel metaphor) is an example of a linguistic stimulus that may involve rule violation and nevertheless become a resource for the cognitive system by becoming incorporated into the semantic system.

According to Dascal, the possibility of precision afforded by the rule-based aspects of natural languages should not make us overlook the wide variety of linguistic means for expressing indeterminacy, including indefiniteness, ambiguity, polysemy, unspecificity, imprecision, and vagueness. Although these linguistic aspects of language can be considered a hindrance from the point of view of certain cognitive needs, they are an asset from the point of view of other cognitive needs. The latter may include, for example, the need to consider initial vague intuitions during insight problem solving or to conceptualize ambiguous situations. The findings of previous research showing RH involvement in metaphor processing, insight problem solving and the comprehension of lexical ambiguity (e.g., Anaki et al., 1998; Beeman, 1998; Jung-Beeman, 2005; Faust & Kahana, 2002; Faust & Lavidor, 2003) are consistent with this notion of a neural system that complements the rule-based, precise aspects of language.

In a recent work, Pinker (2007) implicitly also differentiates between two kinds of language. One kind of language serves as a tool with a well-defined and limited functionality. Such language has a finite stock of arbitrary signs and grammatical rules that arrange signs in sentences. On one hand, this kind of language provides a means of sharing an unlimited number of combinations of ideas about who did what to whom, and about what is where. On the other hand, because it digitizes the world, this kind of language is a "lossy" medium, discarding information about the smooth multidimensional texture of experience. A second kind of language provides us with access to metaphoric expression and thus allows us to convey the subtlety and richness of sensations like smells and sounds and to express the ineffable aspects of human experience.

This chapter has attempted to make explicit the distinction between the two kinds of language discussed by Pinker implicitly. It has also provided this distinction with a neurolinguistic framework that associates one kind of language with the LH and the other with the RH. In this sense, the RH affords us with the capability of expressing aspects of experience such as "flashes of holistic insight (like those in mathematical and musical creativity), waves of consuming emotions, and moments of wishful contemplation [that] are simply not the kinds of experience that can be captured by the beads-on-a-string we call sentences" (Pinker, 2007, p. 276–267).

Vagueness, ambiguity, and unpredictability are characteristics of the experiences to which Pinker refers. These characteristics are also all central aspects of creative thinking. Creativity is typically defined as the generation or production of ideas that are both novel and useful (e.g. Amabile, 1996; Dietrich, 2004). Because novel metaphoric combinations do not adhere to semantic rules, the outcome of the process by which they are comprehended is relatively unpredictable. Thus, creativity, by nature, is unpredictable. To cope with such creative aspects of language, a neural system that is tolerant of semantic rule violations is advantageous. Furthermore, according to some previous research (Faust & Kravetz, 1997; Schmidt et al., 2007), novel metaphors may be just one example of a more general ability of the RH to process low constraint, less predictable, linguistic expressions. Novel metaphors taken from poetry are probably just a highly ecologically valid example of low constraining linguistic stimuli.

The coarse semantic coding of the RH (Beeman, 1998), reflecting the activation and maintenance of a wide range of meanings and associations, may support linguistic creativity. Thus, when describing creativity, Amabile, Barsade, Mueller, and Staw (2005) and Simonton (1999) note that the larger the number of relevant elements that are activated during processing the higher is the likelihood that unusual associations or solutions will be generated, and the larger is the pool of novel ideas from which to choose. RH coarse semantic coding may thus contribute to RH dominance in tasks that require verbal creativity. Recent reviews on creative thinking support this claim by emphasizing the retrieval of remote associations during creative problem solving (Helie & Sun, 2010) as well as showing higher RH activation for tasks that involve verbal creativity (Mihov et al., 2010).

Furthermore, RH ability to differentiate between relevant and nonrelevant elements has also been shown in previous research. The findings that RH involvement in the processing of unfamiliar linguistic stimuli is highly selective and does not extend to unrelated, meaningless combinations (e.g., Faust & Mashal, 2007; Mashal & Faust, 2005, 2008) suggest that RH semantic processing is not only novel, but also useful, efficiently differentiating between potentially meaningful expressions taken from poetry and useless, unrelated meanings. Genuine creativity requires some emphasis on constraints in order to meet the usefulness/appropriateness criteria (e.g., Wind & Mahajan, 1997) and thus RH language mechanisms seem to fulfill both basic criteria for creativity, novelty and usefulness.

An important aspect of creativity is that, despite or maybe because of its open-endedness, it does entail much hard work and sustained effort over time (e.g. Amabile, 1996). In this respect, the non rule-based semantic system of the RH requires no less resources than does the rule-based, expert semantic system of the LH. Returning to *Through the Looking Glass*, this hard work is acknowledged by Humpty Dumpty. Following his extremely flexible, unusual use of word meanings and in response to Alice's complaint "that's a great deal to make one word mean," he responds that "when I make a word do a lot of work like that . . . I always pay it extra" (p. 82). This extra pay may refer to the integration of left and right hemisphere semantic processes, which allows us access to the rich resources provided by our linguistic capacity.

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