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Metaphor Comprehension and the Brain: Empirical Studies

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"Don't know what you've got 'till it's gone; they've paved paradise, and put up a parking lot." -Joni Mitchell

During lunch one afternoon in the fall of 1990, retired New York Times reporter A.H. Raskin felt a strange sensation in his right arm, and slowly slipped out of consciousness. When he awoke again in New York Hospital, his world would never be the same. Raskin had suffered a stroke that resulted in damage to the front portion of his left hemisphere. As a result, he was unable to move his right arm and leg, unable to speak, and unable to understand even the simplest language. Eventually, Raskin regained the ability to walk, to move his arm, and to understand what was said to him. Though he did his best to produce nouns and verbs together in an order that others might make sense of, fluent speech remained a challenge for him the rest of his life (Raskin, 1992).

Raskin suffered from Broca's aphasia, a language disorder often accompanied by weakness or paralysis of the right side of the body. Broca's aphasics have largely intact comprehension abilities, but can speak only with effort, typically producing short, telegraphic phrases. The condition is named after 19th century neurologist Paul Broca who prompted scientific discussion as to whether language ability could be localized in the brain with his classic report of two patients with profound communicative deficits following large left frontal lobe lesions (Broca, 1865). Localization received further support from Broca's contemporary, Wernicke, who reported two patients with severe language comprehension deficits, apparently due to the presence of a lesion in the posterior portion of the left temporal lobe (Wernicke, 1874). Although Wernicke's aphasics can speak fluently, their speech includes made-up words known as paraphasias (e.g. "treen" for "train"), and their sentences are often incoherent. In contrast, the incidence of aphasic deficits in patients with lesions in the right hemisphere is far less common (Hecaen & Consoli, 1973).

Cognitive neuroscientists' understanding of the relationship between brain activity and language ability derives largely from the study of brain injured patients. Since damage to the front portion of the brain is associated with difficulty speaking, it is assumed that left frontal areas play a crucial role in language production. Similarly, since damage to the posterior portion of the brain is associated with difficulty understanding language, it is assumed that left posterior temporal areas play a crucial role in language comprehension. The logic is that the damaged area plays a critical role in the compromised function. Consequently, the left hemisphere (LH) is considered to be the language hemisphere, while the right hemisphere (RH) is the "minor" hemisphere.

However, language deficits have also been associated with damage to the RH. In contrast to the severe language impairment in patients with left hemisphere damage (LHD), patients with RHD exhibit more subtle deficits involving the relationship between an utterance and its context. RHD production, for example, is marked by socially inappropriate remarks, tangential speech, digressions of topic, combined with a failure to utilize nonverbal cues (Joanette, Goulet, & Hannequin, 1990). In experimental studies of their comprehension, RHD patients have been shown to have difficulty understanding jokes (Bihrle, Brownell, & Gardner, 1986; Brownell, Michel, Powelson, & Gardner, 1983), interpreting sarcastic utterances (Giora, Zaidel, Soroker, Batori, & Kasher, 2002; Rehak, Kaplan, & Gardner, 1992), and have been characterized as deriving overly literal interpretations of metaphoric language (Winner & Gardner, 1977). Thus the left hemisphere is associated with language processing traditionally construed as linguistic, that is to say, phonological, syntactic, and semantic analysis, while the right hemisphere has been associated with processing typically construed as pragmatic, or extra-linguistic.

The role of the two hemispheres in metaphor comprehension thus has potential implications for the dispute in cognitive science as to whether metaphor should be considered the province of semantics or pragmatics. According to traditional views, metaphor represents a departure from normal, that is to say, literal, language use and thus falls within the province of pragmatics (Grice, 1975; Searle, 1979). However, others have argued that metaphoric meanings undermine the very distinction under dispute, that between linguistic and nonlinguistic meanings. Ordinary language is replete with metaphors of varying degrees of entrenchedness (Gibbs, 1994; Lakoff & Johnson, 1999; Sweetser, 1990; Turner, 1991). Moreover, the recruitment of real world knowledge and local contextual information is necessary for the comprehension of both literal and metaphorical meanings (Coulson, 2000; Gibbs, 1994; Gibbs & Gerrig, 1989).

In view of this dispute, the question of whether metaphor comprehension is subserved by the right or the left hemisphere of the brain assumes theoretical importance. If metaphorical meanings can be construed as “residing” in the right hemisphere, metaphor could be considered pragmatic, extra-linguistic knowledge. However, as outlined below, the exclusive association between RH damage and metaphor comprehension deficits is rather equivocal. Moreover, the neuropsychological studies on which this association rests have some inherent limitations. For one thing, brain damage can lead to functional reorganization as well as compensatory strategies that produce qualitative changes in language processing. These factors make it difficult to infer the division of labor in normal language processing solely from a description of patients' deficits. Optimally, the study of brain injured patients is accompanied by other techniques to assess the neural substrate of language comprehension. These include the use of neuroimaging technologies such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) to study how different sorts of language tasks affect metabolic activity in the various parts of the healthy brain. Similarly, the visual half-field priming paradigm, employed successfully with commissurotomy ("split brain") patients, has also been used with normal healthy adults to study hemispheric differences in language processing.

Perhaps because of the theoretical implications of the RH as the preferred neural substrate of metaphor comprehension, this issue has received the most attention from cognitive neuroscientists. However, in recent years cognitive neuroscientists have increasingly used measures of brain function to address the validity of more detailed models of metaphor comprehension proposed by cognitive psychologists. Below, in sections 2 and 3, we review evidence for and against the idea that the RH plays a crucial role in metaphor comprehension. In section 4, we discuss the use of electrophysiological measures to assess the real-time processing of metaphors. In section 5, we look to the future and speculate about how the study of the brain might enhance our understanding of metaphor comprehension.

2. RH role in metaphor comprehension

The proposal that the RH plays an important role in metaphor comprehension has its roots in the study of brain injured patients. However, it has also received support from the study of neurologically intact adults via the visual half-field paradigm and functional neuroimaging techniques. In this section, we review evidence consistent with the RH metaphor view from each of these sources of information.

2.1 Patient Studies

The characterization of RHD patients as being overly literal in metaphor interpretation originates in a study done by Winner & Gardner (Winner & Gardner, 1977) in which they asked RHD patients to match sentences such as "He had a heavy heart," to a pictorial depiction from an array that included an illustration of the literal meaning of the phrase (a man lifting an oversized heart), the metaphoric meaning (a man crying), and different aspects of the literal meaning (a picture of a large weight, a picture of a heart). While RHD and LHD patients were both impaired relative to normals, the RHD patients were more likely to err by choosing the literal foils, that is, the man stumbling under the weight of the massive heart. In a similar task, LHD aphasic patients were better able to match words such as "wealth" with connotative pictorial representations, such as an arrow pointed up or down, than were RHD patients (Gardner & Denes, 1973) . Further, in a comparison of RHD and LHD patients' language abilities, Van Lancker & Kemplar (1987) found that while both groups performed well in the comprehension of single words, and RHD patients were better able to comprehend novel sentences, the LHD patients were better able to comprehend familiar idiomatic phrases. Given that LHD patients tend to have more obvious language deficits than their RHD counterparts, the finding that LHD patients actually perform better than those with RHD on figurative language comprehension tasks points towards a special role for the RH in figurative language comprehension.

However, one possible reason for the superior performance of LHD patients on these tests of figurative language comprehension is that the comprehension tasks all involved picture matching. While the pictures might be expected to serve as an additional source of information for LHD aphasics, they might actually complicate the task for RHD patients as damage to the RH is often associated with visuo-spatial deficits. However, RHD patients have also been shown to have problems with metaphoric meanings in purely verbal paradigms. For example, Brownell and colleagues gave participants word triads, such as *cold-hateful-warm*, and asked them to pick the two words that had the same meaning, or that went together better (Brownell, 1984; Brownell, Simpson, Bihrle, Potter, & Gardner, 1990). Semantic relationships between the words were based on either denotative relationships, such as the antonymy between *cold* and *warm*, connotative relationships, such as that between *cold* and *foolish*, metaphoric relationships as in *cold* and *hateful*, or were unrelated as in *cold* and *wise*. RHD patients showed normal use of antonym association, but less than normal use of metaphoric equivalence; LHD patients showed the opposite pattern (Brownell, 1984)

An alternative explanation, however, is that the RHD deficit lies in appreciating the less frequent meaning of an ambiguous word, rather than the appreciation of metaphoric meanings, *per se*. To address whether the RHD deficit could be attributed to the appreciation of the less frequent meaning of an ambiguous word, Gagnon and colleagues tested metaphoric adjectives as well as non-metaphoric, but ambiguous, nouns (c.f. Brownell et al., 1990). Relative to normal controls, both RHD and LHD patients' performance was impaired. Although performance of both groups was comparable on the metaphoric adjectives, RHD patients outperformed the LHD patients on the nonmetaphoric nouns (Gagnon, Goulet, Giroux, & Joanette, 2003). While the LHD patients' deficits argue against the idea that metaphor comprehension is the exclusive province of the RH, these data suggest that metaphoric meanings pose a particular problem for RHD patients. In sum, these studies suggest that damage to the LH decreases one's sensitivity to literal aspects of word meaning, and increases dependence on connotative and metaphoric aspects of word meaning. Damage to the RH, by contrast, seems to increase one's dependence on literal aspects of word meaning at the expense of sensitivity to metaphor and connotation (Brownell, 2000).

2.2 Visual Half-Field Priming

One technique that has been used to investigate the role of the right hemisphere in neurologically intact individuals is the visual half-field priming paradigm. By presenting stimuli outside the center of gaze, it is possible to selectively stimulate visual cortex in the left or right hemisphere. In normal individuals, the information is rapidly transmitted to other brain regions, including those in the other hemisphere. Nonetheless, differences in the initial stages of processing can indicate hemisphere-specific computations (Chiarello, 1991). Presumably because reading is primarily supported by LH activity, lexical decision times (the amount of time it takes a participant to judge whether or not a string of letters forms a real word) are typically shorter with presentation to the right visual field (RVF/LH). However, priming effects – the difference in response times to related and unrelated words – are sometimes larger with presentation to the left visual field (LVF/RH), depending on the sorts of materials. Larger priming effects with RVF/LH presentation are typically interpreted as indicating a LH bias for the materials, while larger LVF/RH priming effects indicate an RH bias.

Research in the visual half-field paradigm has suggested the two hemispheres play different, complementary roles in language processing (Beeman & Chiarello, 1998). Chiarello, for example, has suggested that linguistic input results in automatic semantic activation in both hemispheres, but that only the LH engages in post-lexical integration processes (Chiarello, 1985). Moreover, semantic activations in the LH are more specific than in the RH, and subject to inhibitory processes (Chiarello, 1988). This portrait of focused semantic activation in the LH, and more disparate activations in the RH is supported by a study of semantic paralexias produced by normal participants when words were laterally presented (Rodel, Landis, & Regard, 1989). Further, whereas both hemispheres show priming for closely associated words, the RH is more likely to show priming when the relationship between words is more oblique (Beeman & Chiarello, 1998).

Beeman and colleagues explicitly link RHD patients' impaired performance on pragmatic language comprehension tasks such as metaphor comprehension to differences in semantic activations in the two hemispheres of the brain (Beeman et al., 1994). Alluding to hemispheric differences in the size of receptive fields in the visual system (Marsolek, Kosslyn, & Squire, 1992), Beeman and colleagues suggest semantic representations in the LH are fine coded, while those in the RH are coarsely coded. These investigators speculate that while information activated by the LH is usually adequate to connect discourse elements, information activated in the RH can be crucial for connecting elements that are distantly related. RHD patients' deficits in metaphor comprehension might, then, result because the pertinent information is not activated in the RH. Similarly, Brownell (2000) suggests the RH contribution to metaphor comprehension is diffuse activation across a loosely organized semantic network that is not actively suppressed, and consequently can result in the formation of distant associations needed to understand metaphors.

Using the visual half-field priming paradigm to examine hemispheric asymmetries in the processing of metaphoric language, Anaki and colleagues had participants read centrally presented words with literal and metaphoric meanings, and then make lexical decisions to laterally presented target words (Anaki, Faust, & Kravets, 1998). If the prime was "stinging", for example, the target might be a word such as "bee" that related to the literal meaning of the prime, or a word such as "insult" that related to the prime's metaphorical meaning. Target words appeared either, 200 ms after the onset of the prime, thought to index automatic processing, or 800 ms after the onset of the prime, thought to index later, more controlled, stages of processing. At the short stimulus onset asynchrony (SOA), both literal and metaphorical meanings were primed with presentation to the RVF/LH, and the metaphorical meaning was primed with presentation to the LVF/RH. At the longer SOA, Anaki and colleagues found priming for the literal meaning with presentation to the RVF/LH, and priming for the metaphorical meaning with presentation to the LVF/RH. These researchers have argued that their findings suggest metaphoric meanings are initially activated in both cerebral hemispheres, and subsequently decay rapidly in the LH, while being maintained in the RH.

2.3 Neuroimaging

Another technique for assessing the functional role of various brain regions in healthy people is neuroimaging. Imaging techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) are used to detect brain regions in which different experimental conditions are associated with increased metabolic activity. Though metaphor comprehension has received little attention from neuroimagers, one classic PET study of metaphor comprehension supports the view of the RH as being preferentially involved in this aspect of language comprehension.

Bottini and colleagues collected PET data from neurologically intact adults as they read blocks of literal and metaphorical sentences (Bottini et al., 1994). In this study, participants judged whether literal sentences were plausible ("The boy used stones as paperweights,") or implausible ("The lady has a bucket as a walking stick,"). In the metaphor condition, participants judged whether metaphors were interpretable ("The old man had a head full of dead leaves,") or uninterpretable ("The investors were trams,"). Both literal and metaphorical sentences activated LH areas in the prefrontal and basal frontal cortex, middle and inferior temporal gyri, temporal pole, parietal cortex, and precuneus (Bottini et al., 1994). These areas are often activated by sentence comprehension tasks (Bookheimer, 2002).

However, metaphor comprehension was also associated with increased RH activation in pre-frontal cortex, the middle temporal gyrus, the precuneus, and the posterior cingulate (Bottini et al., 1994). Activations in the right precuneus have previously been attributed to conscious inspection of mental images, while prefrontal activation has been argued to reflect the difficulty of a decision task (Fletcher, Shallice, Frith, & Frackowiak, 1996). Bottini and colleagues argue that the prefrontal activations reflect retrieval from episodic memory, and the precuneus activation reflects increased mental imagery associated with metaphor comprehension. They speculate that these activations result because metaphor comprehension requires the retrieval of imageable experiences from episodic memory.

3. The case against RH metaphor comprehension

3.1 Neuroimaging

The PET study that shows RH activations during metaphor comprehension (Bottini et al., 1994), though suggestive, is qualified by limitations of the block design (D'Esposito, Zarahn, & Aguirre, 1999), and to a lesser extent by constraints on the spatial resolution of PET (Roland, Kawashima, Gulyas, & O'Sullivan, 1995). A recent event-related fMRI study revealed no evidence of preferential RH activation to metaphor comprehension (Rapp, Leube, Erb, Grodd, & Kircher, 2004). Rapp and colleagues asked healthy adults to read simple metaphorical statements or literal statements with the same syntactic structure. For example, the metaphor “The lovers’ words are harp sounds,” had the following literal counterpart, “The lovers’ words are lies,”. Participants’ task was to judge whether each sentence had a positive or negative connotation (matched across literal and metaphorical sentences). Relative to literal statements, metaphors activated left inferior frontal cortex, inferior temporal gyrus, and posterior middle temporal gyrus. No RH activation was observed.

One difference between the PET study that revealed RH activation for metaphors and the fMRI study that did not is that task difficulty in the literal and metaphorical sentences was well-matched in the latter (Rapp et al., 2004), but not the former (Bottini et al., 1994). Consequently, RH recruitment may depend on overall task difficulty, rather than the figurativity of the meanings. Other fMRI studies in healthy adults indicate that when literal sentence comprehension places increased demands upon lexical and syntactic processes it results in increased activation both in classic LH language areas and in their RH homologues (Keller, Carpenter, & Just, 2001). In general, RH activation is associated with complex sentences and discourse level processing (Bookheimer, 2002; Kircher, Brammer, Andreu, Williams, & McGuire, 2001; St. George, Kutas, Martinez, & Sereno, 1999), suggesting it is semantic complexity that triggers the recruitment of RH areas. RH activation in metaphor comprehension tasks, then, might not reflect the retrieval of metaphoric meanings from the RH. Rather, RH activations might simply result because the semantic complexity of metaphors is greater than that of their literal controls.

3.2 Visual Half Field Studies

Further, in contrast to the visual half-field study that suggests metaphoric meanings are preferentially activated in the RH (Anaki et al., 1998), researchers using sentential stimuli found evidence that suggests metaphor comprehension involves both left and right hemisphere processing (Faust & Weisper, 2000). Faust and Weisper showed participants centrally presented sentence fragments such as “My job is a” followed by the lateralized presentation of a target word. Target words could make the sentence literally true, literally false, or metaphorically true. Participants were asked to judge the literal truth-value of the sentences – and thus respond "no" to the metaphoric endings. Results showed that regardless of which visual field the target was presented to, a metaphor interference effect was observed. That is, "no" responses to metaphoric endings were slower and less accurate than those to the literally false endings, suggesting the metaphoric meaning was available in both hemispheres to produce response conflict. Moreover, in contrast to earlier work by Anaki and colleagues, the metaphor effects reported by Faust and Weisper (Faust & Weisper, 2000) were more pronounced with presentation to the RVF/LH.

In fact, subsequent attempts to replicate results reported by Anaki and colleagues have failed. Using English materials, Kacinik (2003) found literal (stinging BEE) and metaphor (stinging INSULT) priming with RVF/LH presentation at short SOAs, but only literal priming with an 800 ms SOA; with LVF/RH presentation, literal priming was observed at SOAs of 100, 200, and 800 ms, while metaphor priming was evident only in accuracy scores, suggesting the activation of the metaphoric meaning in the RH was weak, at best. When the adjective-noun pairs were presented in sentence contexts, RVF/LH literal and metaphor priming was observed after both ambiguous ("Andrea obviously wasn't aware of the icy SLOPE/GLARE,") and unambiguous ("I lost my balance on the icy SLOPE/GLARE," vs. "Ben turned his head only to see her icy GLARE/SLOPE,") sentence primes (Kacinik, 2003). Similarly, with LVF/RH presentation, literal and metaphor priming was observed after both sorts of sentence primes, though priming effects were larger after the unambiguous sentences (Kacinik, 2003). These results suggest metaphoric meanings are available to both the LH and the RH.

Kacinik (2003) also addressed hemispheric asymmetry in the processing of more complex sentential metaphors such as “The train I take to work is a bullet,” by testing for hemifield priming of probes related to the literal (KILLED) and metaphorical (FAST) meaning of the sentence final noun. Probes (e.g. JAWS) were preceded either by a consistent sentence prime, (e.g. “The lifeguard thought he saw a shark,”) or an inconsistent one, (e.g. “The lawyer they’ve hired is a shark,”). Priming was observed bilaterally for both literal and metaphorical meanings in consistent contexts. Inconsistent probes were never primed with RVF/LH presentation. Further, while inconsistent literal probes were primed in the LVF/RH, inconsistent metaphorical probes were not. Though these data support the idea that semantic activations in the RH are somewhat less sensitive to context than in the LH, they argue against the RH as the preferred substrate of metaphor comprehension. Indeed, recent work in the visual half-field priming paradigm suggests both hemispheres have the capacity to comprehend metaphorical meanings.

3.3 Patient Studies

The original studies reporting impaired metaphor comprehension in RHD patients have been criticized for several methodological shortcomings (see e.g. Joanette et al., 1990). For example, in their landmark “heavy heart” study, Winner & Gardner (1977) did not assess whether perceptual deficits often associated with RHD affected patients’ task performance. Indeed, in many such studies, perceptual deficits are not assessed, and even the language abilities of the patients are not studied in detail (see Oliveri, Romero, & Papagno, 2004 for critique). The number of subjects is typically quite small, as is the number of stimuli. Further, because many of the studies that support the view of RHD metaphor comprehension deficits have used forced choice paradigms, some researchers have suggested the RHD deficit lies not in comprehension, per se, but in rejecting the alternative meanings of the experimental stimuli.

Indeed, RHD metaphor comprehension impairments are most evident in tasks that require controlled strategic processing. For example, Tompkins (1990) used an auditory word priming paradigm to test both automatic and controlled aspects of word processing. As is customary, this was achieved by varying the amount of time between the onset of the prime and the target words (known as stimulus onset asynchrony, or SOA). When SOA is short, performance reflects fast-acting automatic processes; when SOA is longer, performance reflects slower controlled processes. At the short, but not the long, SOA, ambiguous primes facilitated performance for both literally and metaphorically related targets, suggesting RHD patients can access the metaphoric meanings of words, but are impaired in the strategic use of semantic knowledge (Tompkins, 1990). Similarly, both RHD and LHD patients performed normally on an on-line word monitoring test of idiom comprehension, but were impaired on an off-line idiom definition measure (Tompkins, Boada, & McGarry, 1992). These findings suggest that while both hemispheres are sensitive to word-level metaphoric meaning, task demands can impact performance due to limited attentional and memory resources in these patients.

Such limitations may particularly affect performance on picture matching as there is considerable evidence that these tasks underestimate patients' metaphor comprehension abilities. A more recent test of a large number of RHD participants' metaphor comprehension abilities showed that although RHD patients were significantly impaired on both a picture-matching and a verbal task, their impairment on the picture matching task was more severe (Rinaldi, Marangolo, & Baldassarri, 2002). As in Winner & Gardner (Winner & Gardner, 1977), RHD participants were able to verbally explain the meaning of statements for which they had chosen the incorrect literal picture (Rinaldi et al., 2002). Other investigators have found that even neurologically intact participants perform better on verbal tests of figurative language comprehension than on tests that involve picture matching (Papagno, Tabossi, Colombo, & Zampetti, 2004). Further, in a test of both LHD and RHD patients, while LHD performance on verbal and pictoral subtests were correlated, RHD performance was not, suggesting non-linguistic factors may contribute to this dissociation (Zaidel, Kasher, Soroker, & Baroti, 2002).

Indeed the ability to understand figurative language is compromised not only by unilateral lesions in the RH, but also by other neurological conditions. As noted above, both LHD and RHD individuals are impaired on tests of figurative language comprehension (Gagnon et al., 2003; Papagno et al., 2004). Unlike their RHD counterparts, LHD patients have been shown to be impaired both on picture matching tasks and on a task that requires them to give a verbal explanation of idiom meaning (Papagno et al., 2004). Giora and colleagues (Giora et al., 2002) found that RHD patients performed better than LHD patients on a test of the comprehension of highly conventional metaphors – though not on a test of sarcasm comprehension. Moreover, these investigators found that metaphor comprehension was negatively correlated with lesion extent not in the right hemisphere, but, rather, in the left middle temporal gyrus and the area surrounding the left supramarginal and superior temporal gyri (also known as Wernicke’s area).

In fact, the study of patients with agenesis of the corpus callosum (ACC), has shown that metaphor comprehension can be impaired even in individuals with damage to neither side of the brain (Paul, Van Lancker-Sidtis, Schieffer, Dietrich, & Brown, 2003). In this condition, the corpus callosum, the fiber tract that connects the two hemispheres, does not develop, but brain maturation is otherwise relatively normal. In a study of a large sample of these patients with normal IQ stores, Paul et al. (2003) found that individuals with ACC performed normally on tests of literal language comprehension, but were impaired on tests of formulaic, nonliteral language. Moreover, as in the idiom comprehension deficits of RHD patients, the ACC patients tended to err by picking a literal depiction of the idiomatic phrase. The similarity between performance of RHD patients and ACC patients with intact RHs indicates a crucial role for interhemispheric interaction in idiom comprehension.

Impaired idiom comprehension in the face of largely intact literal language comprehension has also been observed in individuals with conditions that compromise executive functions, such as Down's syndrome (Papagno & Vallar, 2001), and Alzheimer's disease (Papagno, 2001). To address the relationship between executive functions and idiom comprehension, Papagno, Lucchelli, Muggia, & Rizzo (2003) subjected patients with Alzheimer's disease (AD) to a wide battery of tests that assessed their language abilities, executive function (via a dual task performance paradigm), and idiom comprehension using a picture matching task. As a group, AD patients performed fairly comparably with healthy controls on the literal language tests, but worse than controls on the idiom task. When the literal depiction of the idiom was plausible, AD patients tended to incorrectly choose it, suggesting they encountered difficulty suppressing a plausible, related literal interpretation of idiomatic phrases. Further, though literal sentence comprehension scores were not correlated with performance on any other tests, idiom comprehension scores correlated with performance on the dual-task. The detrimental effect of AD on central executive functions can negatively impact figurative language comprehension by impairing the ability to suppress literal meaning.

3.4 Repetitive transcranial magnetic stimulation

Although the study of brain injured patients has been an invaluable source of information for cognitive neuroscientists, there are some inherent limitations to this method. Lesion size and location can vary drastically among the members of a patient group, complicating inferences about the cause of any observed deficits. People also differ in their degree of neural plasticity, or the extent to which the brain can 'rewire' itself to compensate for the damaged tissue. Indeed, plasticity makes it difficult to infer whether preserved language function reflects activity in the reorganized brain, or the normal ability of the spared tissue. However, these limitations are much less of a factor in a technique known as repetitive transcranial magnetic stimulation (rTMS).

Used on neurologically intact adults, rTMS involves transmitting a series of magnetic pulses to the scalp in order to disrupt the underlying brain activity. In these experiments, participants undergo stimulation to particular scalp regions (either with a real series of magnetic pulses, or a "sham" series), and subsequently perform a cognitive or language task. Although the disruption is transient and fully reversible, its effect on cognitive activity can be used to infer the importance of the affected brain area for the cognitive process being tested. rTMS allows the cognitive neuroscientist to test the effects of disrupting activity in a relatively small, targeted area of an otherwise normal brain.

Oliveri and colleagues (Oliveri et al., 2004) used rTMS to disrupt activity in right and left frontal and temporal brain areas while participants did a picture matching task. Sentences involved either opaque idioms ("He is in shape,") or literal controls, ("He is drawing,"). Pictures included either a depiction of the idiomatic interpretation (a picture of a man showing off his muscles) or a potential literal interpretation of the same sentence (a mouse embedded in a geometric wedge of cheese). Pictures for the literal sentences were either literal depictions of the sentence (a boy drawing), or an identical picture save one detail (a picture of a boy approaching a canvas). rTMS was applied over left and right temporal and frontal cortex.

Left frontal rTMS induced a small but significant impairment, but right frontal rTMS did not (Oliveri et al., 2004). Further, left temporal rTMS disrupted performance on both literal sentences and idioms, while right temporal rTMS actually facilitated performance on both idioms and literal sentences. This facilitation may result because homologous LH areas were disinhibited, suggesting a critical role for left temporal areas in performance of this task. These studies suggest LH temporal lobe activity is critical for idiom comprehension. Thus neuropsychological studies that point to the importance of the RH for idiom processing may instead reflect a generalized reduction in processing capacity (e.g. working memory and attentional resources). In the face of reduced resources, patients resort to strategies that result in their preference for literal depictions.

4. Real time comprehension of metaphors

The neurophysiology of language processes can also be investigated via the non-invasive recording of event-related brain potentials (ERPs). ERPs are small voltage fluctuations in the electroencephalogram (EEG) that are timelocked to perceptual, motor, or cognitive events collected by recording EEG while participants perform a cognitive task such as reading (Rugg & Coles, 1995). By averaging the EEG timelocked to multiple tokens of a given type (e.g. the onset of a word used metaphorically), it is possible to isolate aspects of the electrical signal that are temporally associated with the processing of that type of event (such as understanding a metaphoric meaning). The result of averaging is a waveform with a series of positive and negative peaks, known as components, and labeled by reference to their polarity ('P' for positive-going and 'N' for negative-going), and when they occur relative to the onset of the stimulus event, or relative to other ERP components.

Over the last 25 years, cognitive neuroscientists have identified ERP components associated with processing different sorts of linguistic information, such as the link between the N400 and semantic integration processes. The N400 component of the ERPs was first noted in experiments contrasting sentences that ended sensibly and predictably with others that ended with an incongruous word. Congruous words elicited a late positive wave, while incongruous endings elicited a negative wave beginning about 200 ms after word onset and peaking at 400 ms (Kutas & Hillyard, 1980). Subsequent experiments have shown that finer gradations of semantic context also modulate N400 amplitude. For example, amplitude shows a strong inverse correlation with the predictability of the eliciting word within a given sentence context (Kutas, Lindamood, &

Hillyard, 1984). In general, experimental manipulations that make semantic integration more difficult result in larger amplitude N400, while those that facilitate it result in smaller N400.

Because ERPs provide an on-line index of brain activity related to language comprehension, they have been used to test various models of metaphor comprehension. Pynte and colleagues (Pynte, 1996), for example, used ERPs to address the validity of three hypotheses about metaphor comprehension: the standard model, the parallel hypothesis, and the context-dependent hypothesis. First, the *standard pragmatic model* posits two discrete stages of metaphor processing, as metaphorical meanings are accessed only after the literal meaning has been rejected. This model predicts an initial effect of metaphoricity on the N400, reflecting the literal incongruity, followed by a later ERP effect, reflecting the access of the metaphorical meaning. However, although metaphors ("Those fighters are LIONS,") elicited slightly larger N400s than literal controls ("Those animals are LIONS,") there were no reliable ERP effects after the N400, viz. between 600 and 1200 ms after the onset of the sentence final word. Pynte and colleagues thus suggested that the enhanced N400 to the metaphors reflected participants' apprehension of the literal incongruity of these sentences, as predicted by the standard model. However, the absence of late ERP effects is contrary to the predictions of that model.

In contrast to the standard model, the *parallel hypothesis* is that literal and metaphorical meanings are processed in parallel. According to the parallel model, if N400 amplitude reflects the difficulty of comprehending literal meanings, it should also reflect the difficulty of comprehending metaphorical meanings. The parallel model thus entails that differences in the comprehensibility of familiar versus unfamiliar metaphors should be reflected in N400 amplitude. However, when presented out of context, Pynte et al. found no differences in ERPs elicited by familiar metaphors such as “Those fighters are LIONS,” and unfamiliar metaphors such as “Those apprentices are LIONS.”

The *context-dependent hypothesis* is the idea that the metaphorical meaning is directly accessed when it is relevant to the preceding context. To test this hypothesis, Pynte and colleagues recorded ERPs as participants read sentences with familiar and unfamiliar metaphors placed in either relevant (e.g. for the lion example, “They are not cowardly,”) or irrelevant (e.g. “They are not idiotic,”) contexts. The context-dependent hypothesis predicts that regardless of the familiarity of the metaphor, the relevance of the context should modulate N400 amplitude. Accordingly, Pynte et al. found that while metaphor familiarity did not affect the ERPs, the relevance of the context did. Compared to the relevant contexts, metaphors in irrelevant contexts elicited more negative ERPs in both the N400 window and the subsequent 600-100 ms interval, suggesting irrelevant metaphors were more difficult to process.

Further evidence that metaphorical meanings are activated very early in the processing stream comes from an ERP study of the metaphor interference effect (MIE). As described above (see section 3.2), the MIE is elicited in a sentence verification paradigm in which the subject is given a literally true, literally false, and metaphorically true (but literally false) sentences. The MIE refers to the increased response times to reject metaphorically true sentences such as, “The divorce is a nightmare,” compared to literally false sentences such as “The divorce is a table,” (Glucksberg, Gildea, & Bookin, 1982). Because the task demands that the participant attend only to the literal meaning of these sentences, the MIE is interpreted as reflecting the automatic activation of metaphoric meanings.

Kazmerski and colleagues (Kazmerski, Blasko, & Dessalegn, 2003) recorded ERPs as healthy participants judged the literal truth of sentences such as “Tulips grow from a bulb,” “The beaver is a lumberjack,” and “The rumor is a lumberjack.” They observed an MIE in participants’ reaction times, as it took participants longer to respond “no” to the metaphorical sentences than their literal counterparts. Interestingly, the MIE was only 11 ms in participants with low IQ (<100), but was 35 ms in participants with high IQ (>115). The ERP correlates of the MIE included a smaller N400 for the metaphorically true sentences than the literally false sentences, suggesting participants found metaphorical words easier to process than the anomalous endings, as well as a larger late positivity for the metaphors, perhaps reflecting the greater difficulty in responding “no” to these items. Moreover, these ERP effects were marked and robust in the high IQ group, but largely absent in the low IQ group whose behavioral MIE was also negligible.

Research to date thus suggests that, contrary to the Standard Model of metaphor comprehension, metaphoric meanings are available quite early in processing, affecting the ERPs beginning 250-300 ms after the onset of a metaphorical word (Kazmerski et al., 2003; Pynte, 1996). Decontextualized metaphors elicit slightly larger N400s than plausible literal controls such as “Those animals are lions,” (Pynte, 1996), suggesting they place more demands on semantic integration processes. However, metaphors elicit smaller N400s than implausible literal controls such as “The rumor is a lumberjack,” (Kazmerski et al., 2003), suggesting they are easier to process than incongruous sentence completions. This latter finding casts doubt on the suggestion that the enhanced N400 (relative to plausible literal endings) elicited by metaphors indexes their literal incongruity.

Coulson & Van Petten (2002) have suggested that N400 amplitude to metaphors is driven by the complexity of mapping and blending operations involved in the comprehension of metaphors, but also in the comprehension of literal language. In our model, metaphor comprehension involves coordinating various conceptual domains in a *blend*, a hybrid model that consists of structure from multiple conceptual domains, and that often develops emergent structure of its own. Metaphor comprehension involves the temporary construction of simple cognitive models along with the establishment of mappings, or, systematic correspondences among objects and relationships represented in various models. Mappings are based on relationships such as identity, similarity, or analogy. Consequently, metaphoric meanings – that use analogy to link objects in different spaces – do not fundamentally differ from meanings that employ other sorts of mappings.

For instance, understanding the metaphor in “All the nurses at the hospital say that surgeon is a butcher,” requires coordinating conceptual structure associated with surgery, butchery, and a blend of the two. To understand this metaphor it is necessary to apprehend mappings between surgeon and butcher, patient and dead animal (e.g. cow), as well as scalpel and cleaver. However, it also involves construction of a blended model that integrates some information from each of the two domains. In this example, the blend inherits goals of the surgeon, and the means and manner of the butcher. The inference that the surgeon is incompetent arises when these structures are integrated to create a hypothetical agent with both characteristics.

Similar conceptual operations are involved in understanding literal language. For example, understanding butcher in "During the war, that surgeon had to work as a butcher," also requires the comprehender to establish mappings and integrate information about a surgeon's training and skill with general information about butchers, and other aspects of the context (Coulson & Matlock, 2001). One might for instance, infer that the surgeon in question was overqualified for his job, or that he was forced to work as a butcher in a labor camp. Differences in the comprehensibility of these *butcher* sentences, then, might be less a matter of their figurativity than the extent to which they require the comprehender to activate additional information to establish mappings and elaborate the blend.

To test these ideas, Coulson & Van Petten (2002) compared ERPs elicited by words in three different contexts on a continuum from literal to figurative, as suggested by conceptual integration theory (Fauconnier, 1998). For the literal end of the continuum, they used sentences that prompted a literal reading of the last term, as in "He knows that whiskey is a strong intoxicant." At the metaphoric end of the continuum, they used sentences such as "He knows that power is a strong intoxicant." The literal mapping condition, hypothesized to fall somewhere between the literal and the metaphoric uses, involved sentences such as, "He has used cough syrup as an intoxicant." Literal mapping stimuli employed fully literal uses of words in ways that were hypothesized to include some of the same conceptual operations as in metaphor comprehension. These sentences described cases where one object was substituted for another, one object was mistaken for another, or one object was used to represent another – all contexts that require the comprehender to set up a mapping, that is, understand a correspondence, between the two objects in question and the domains in which they typically occur.

In the time window in which the N400 is observed (300-500 ms post-onset), ERPs in all three conditions were qualitatively similar, displaying similar waveshape and scalp topography, suggesting that processing was similar for all three sorts of contexts. Moreover, as predicted, N400 amplitude differed as a function of the metaphoricity, with literals eliciting the least N400, literal mappings the next-most, and metaphors the most N400, suggesting a concomitant gradient of processing difficulty. The graded N400 difference argues against the literal/figurative dichotomy inherent in the standard model, and suggests processing difficulty associated with figurative language is related to the complexity of mapping and conceptual integration.

5. The neural substrate of metaphor comprehension

Initially, the portrait of the RH as the preferred substrate of metaphor comprehension looked quite compelling. On picture-matching tasks, RHD patients are more likely than their LHD counterparts to choose literal depictions of metaphoric idioms as the best representation of their meaning (Van Lancker & Kempler, 1987; Winner & Gardner, 1977). Further, on verbal tests, while RHD patients are able to understand multiple meanings of ambiguous nouns, they have difficulty accessing the metaphoric meaning of adjectives (Brownell, 1984; Brownell et al., 1990; Gagnon et al., 2003). Visual half-field studies suggest that while metaphoric meanings are initially activated in both hemispheres, they are only sustained in the RH (Anaki et al., 1998). Finally, functional neuroimaging of healthy adults reveals increased activation of RH brain areas during metaphor comprehension (Bottini et al., 1994).

However, as reviewed in section 3, in each case there is evidence against the RH metaphor proposal. Recent functional imaging results reveal that metaphor comprehension activates only LH language areas (Rapp et al., 2004). Visual half-field studies suggest that when metaphors are embedded in sentence contexts, both hemispheres have access to metaphoric meanings (Faust & Weisper, 2000; Kacinik, 2003). Both neuropsychological studies and rTMS research with normals suggests that the crucial brain areas for metaphor comprehension are left temporal lobe areas crucial for normal comprehension of literal language (Giora et al., 2002; Oliveri et al., 2004).

Although the comprehension of metaphoric meanings poses a challenge that is greater than that associated with literal language of comparable syntactic complexity, there does not seem to be much evidence to support a view of metaphor comprehension as involving a qualitatively distinct processing mode. ERP studies of metaphor comprehension suggest metaphoric meanings are active during the same temporal interval as literal meanings (Kazmerski et al., 2003). As in the case of literal language, semantic integration difficulty of metaphoric language is largely a function of contextual support (Pynte, 1996), and may also be attributable to demands of conceptual mapping and blending operations (Coulson & Van Petten, 2002).

Overall, the investigation of the neurological substrate of metaphor comprehension has proceeded at a rather coarse level, and addressed only the most basic of issues. Indeed, most research on this topic treats metaphoric language as a single monolithic category. Metaphors and idioms are frequently lumped together (see Gagnon et al., 2003; Oliveri et al., 2004 for critique). Further, though there are a number of reasons to expect differences in the processing of highly conventional, lexicalized, metaphors and more novel ones (Giora, 1997; Giora et al., 2002), this difference has not been tested with the methods of cognitive neuroscience. Similarly, among novel metaphors there has been no investigation of the impact of conformity to *conceptual metaphors*, abstract patterns of metaphoric mapping such as that between progress and motion along a path, or love relationships and journeys (Lakoff & Johnson, 1999; Lakoff & Turner, 1989).

Further, in view of recent advances in neuroscience that suggest the representation of word meaning extends beyond the classic language areas identified by neuropsychologists (Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Tranel, Logan, Frank, & Damasio, 1997), the neural substrate of metaphor comprehension may depend on the particular source (vehicle) and target (topic) domains of the metaphor. Pulvermuller and colleagues have long argued that the neural representation of word meaning must differ as a function of what those words represent (Braitenberg & Pulvermuller, 1992; Pulvermuller, 1996, 1999). Because we might expect that words for objects would tend to co-occur with the visual experience of those objects, and words for actions would tend to co-occur with motor activity, correlated firing patterns between the neural representations of the wordforms and the associated experiences would result in the establishment of permanent connections between them via simple Hebbian learning (Pulvermuller, 2003). Hebbian learning is a mechanism by which connection strength between two neurons increases as a function of correlated firing.

Similarly, in the neural theory of language (NTL), it has been proposed that language comprehension involves simulating the situation being described (Feldman & Narayanan, 2004). Because the simulation semantics of NTL suggests that cortical networks that subserve the action of grasping also serve as the neural substrate of its meaning, it predicts that neural activations engendered by metaphors will differ as a function of the source domain as networks that subserve the action of grasping are activated to understand the metaphorical meaning of grasp. Conceptual blending theory, which suggests that “grasping an idea” involves the parallel activation of an abstract and a concrete meaning of grasp, also makes this prediction (Coulson & Matlock, 2001).

5.1 The mental number line

Although these predictions have not been tested empirically, there is recent support from cognitive neuroscience for related claims in cognitive linguistics about the sensorimotor grounding of abstract concepts (Lakoff & Nunez, 2000). In particular there is evidence that neural structures that support spatial reasoning are recruited in certain numerical operations, consistent with the metaphorical mapping between numbers and spatial locations inherent in the concept of a number line. Neuroimaging studies, for example, show that right intraparietal areas important for visuospatial processing are consistently activated by number comparison tasks (Chochon, Cohen, van de Moortele, & Dehaene, 1999; Pinel, Dehaene, Riviere, & Le Bihan, 2001). A functional relationship between the representation of numerical quantity and visuospatial processing is also supported by the presence of a *distance effect* for comparisons of both physical size and numerical quantity: the larger the “distance” between the two items, the faster the comparison is made (Foltz, Poltrock, & Potts, 1984). Further, behavioral assessment of number and size comparisons reveals interference between these two dimensions, suggestive of a common representational code (Henik & Tzelgov, 1982). An fMRI study of the neural substrate of the size and numerical distance effects revealed an anterior right intraparietal activation that was similarly affected by differences in numerical value and stimulus size (Pinel, Piazza, Le Bihan, & Dehaene, 2004).

The recruitment of visuo-spatial processing resources for numerical comparisons is perhaps best seen in the effects of *hemineglect* on various arithmetic tasks. Hemineglect is a neurological condition resulting from lesions to the parietal lobe in the RH in which the patient has difficulty attending to objects on the left side of space. When asked to judge whether numeric stimuli were greater or less than 5, patients with neglect were slower to respond to 4 than to 6; when asked to judge whether numeric stimuli were greater or less than 7, patients with neglect were slower to respond to 6 than 8 (Vuilleumier, Ortigue, & Brugger, 2004). Moreover, when asked whether a time presented as a single digit number was later or earlier than 6, participants were slower to respond to numbers greater than 6, than to numbers less than 6. On the first task, then, patients were impaired when making judgments about numbers to the left of the reference number on a linear number line. On the second, patients were impaired when making judgments about numbers to the left of 6 on a clock face.

One task on which hemineglect is apparent is line bisection, in which the participant is asked to mark the mid-point of a line. Patients with neglect tend to place their marks slightly to the right of the midline – presumably because they are unaware of the left-most portion of the line (Bisiach & Vallar, 2000). Zorzi, Priftis, & Umilta (2002) tested RHD patients with and without hemineglect on a variety of arithmetic tasks. All patients scored well on tests of subtraction and number comparison. However, only hemineglect patients were impaired on a test on which they had to estimate the midpoint of two numbers, as they tended to pick a number that was higher than the correct answer. In line bisection tasks, displacement of the midpoint is larger for longer lines (Halligan & Marshall, 1998). Similarly, in the numerical midpoint estimation task, displacement errors were larger for larger intervals such as 21-29 than for smaller intervals such as 21-25. Analogous patterns of neglect patients' deficits on the spatial and arithmetic problems points to the neurological reality of a metaphorical mapping between numbers and points on a spatially extended line ordered from left to right.

This mapping is further supported by evidence that experimental manipulations that affect the direction of attention in space affect performance on the midpoint estimation task. Rosetti and colleagues (2004) tested for the cognitive consequences of prism adaptation by having patients with hemineglect perform the midpoint estimation task before and after a session in which they wore prism glasses that shift the visual world by 10 degrees. In addition to the actual prism adaptation session, patients also underwent a sham adaptation period in which they word goggles that had no effect on the visual world. Performance on number bisection was not impacted by wearing the sham goggles, but was reliably improved after prism adaptation, suggesting a functional link between parietal regions involved in the representation of space and numbers (Rossetti et al., 2004).

5.2 Conclusion

As we progress through the 21st century, it will be important to move beyond the traditional question of the right hemisphere's role in metaphor comprehension to address the particular cognitive and neural underpinnings of this complex process. By combining information from the study of brain injured patients with behavioral, electrophysiological, and neuroimaging data from healthy participants, it is possible to learn a great deal about the neural substrate of particular cognitive processes. In this endeavor, however, the question of paramount interest should not be *where*, but *how*. As the study of the mental number line shows, these two pursuits are not mutually exclusive as the localization of multiple cognitive processes in the same brain regions can point to functional commonalities that lead to novel insights. Rather than simply assigning cognitive processes to brain regions, the cognitive neuroscientist should aim to integrate her general knowledge of neurophysiology with processing models of metaphor comprehension in order to achieve a deeper understanding of this important phenomenon.

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