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Neuroimaging contributions to the understanding of discourse processes

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Neuroimaging research is providing new types of information and insight about the cortical activity underlying discourse processing. Knowing the intensity and location of the brain activity during discourse comprehension adds significantly to the information provided by behavioral measures alone. The combination of neuroimaging data and behaviorally based discourse theories indicate that discourse processing is underpinned by a system of several distinguishable cortical networks that are activated for discourse processing, above and beyond the activation evoked by comprehension at the word and sentence level. Whereas the multiplicities of the processes in discourse comprehension are sometimes seen as a drawback to behavioral experiments, it is something of a benefit in neuroimaging research. Controlled neuroimaging experiments, with their multidimensional measures, can help determine when each of these components contributes to discourse processing. By making some assumptions about the cortical regions/network that underlie this processing, we can begin to determine when an area becomes activated and to what degree it is activated as a function of the discourse properties.

In this chapter, we describe some key neuroimaging studies of discourse processing, and observe some systematic patterns of results that apply across the described studies. To foreshadow these patterns, we list here five specialized networks we believe to be involved in discourse processing.

Parallel Networks of Discourse

1. A coarse semantic processing network (right middle and superior temporal)
2. A coherence monitoring network (bilateral dorsolateral prefrontal)
3. A text integration network (left inferior frontal-left anterior temporal)
4. A network for interpreting a protagonist's or agent's perspective (bilateral medial frontal/posterior right temporal/parietal)
5. A spatial imagery network (left dominant, bilateral intraparietal sulcus)

This list should be treated with caution and with excitement. It is exciting that some of the components of discourse processing revealed by neuroimaging research, like protagonist perspective monitoring (here we use protagonist as a shorthand for any agent in the story capable of intentional action), are relatively new to the discourse processing theory (although comprehending the motivations of characters in a story is probably an ancient skill). At the same time, there is uncertainty about the reality of these networks and about their anatomical location. Moreover, these networks must function in interaction with somewhat lower level comprehension processes that operate at the lexical and sentence level (for a review see: Bookheimer 2002; Gernsbacher & Kaschak, 2003). Despite these cautions, it seems useful to consider the recent research with some framework in mind, and we suggest that these five networks/discourse functions provide an initial attempt at such a framework. As we proceed through the chapter we will elaborate on the characteristics of these networks as they are illuminated by the various studies. At the conclusion of the chapter we will expand on a theoretical framework based on these networks.

Although the focus of this paper is decidedly not on "where" in the brain discourse processing occurs, a brief overview of which areas of the brain play a role in discourse comprehension is useful. In almost every discourse processing task, the traditional left hemisphere language network activates in a contrast with a fixation baseline condition. This traditional left hemisphere language network includes the left hemisphere inferior frontal gyrus, the superior and middle temporal gyrus,

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potions of the inferior temporal gyrus and the angular gyrus. In addition to this basic language processing network, we expected additional discourse networks to activate during discourse processing. An overview of the Parallel Networks of Discourse and a rough sketch of the cortical regions in which they are localized are shown in Figure 1. This schematic representation is shown via surface projection on a rendered brain. It is not intended to depict an exhaustive account of discourse processing networks but instead highlight some key areas. It is likely that the networks are differentially engaged in the research presented here and the localization of the peak activation for a specific task could be expected to vary somewhat within an anatomical region.

Discourse theories become critical in developing this understanding of the cortical discourse processing network. In addition, neuroimaging research has led to the development of several new discourse theories such as the coarse coding theory of right hemisphere processing (Beeman, 1998), the dynamic recruitment of networks in response to text constraints (Ferstl, Rinck & von Cramon, 2005; Mason and Just, 2004; Xu et al., 2005), a Theory of Mind system responsible for awareness of different perspectives (Gallagher and Frith, 2003), and the spillover of processing to other differential specialized networks in response to capacity utilization (Just et al., 1996). The cortical activation and these new theories are based on, or at least consistent with, traditional discourse theories such as Kintsch's Construction-Integration framework (1988), Gernsbacher's Structure Building Framework (1990), Myers and O'Brien's Resonance model (1998), Giora's Graded Salience Hypothesis (1997) and van den Broek's Landscape architecture (1996) as well as others.

The Beginnings of Brain Imaging in Discourse Comprehension

Dating back to Broca's and Wernicke's findings on brain-damaged patients with specific language deficits in the late 1800's, psychologists have had some idea of the brain's functioning as a language processing mechanism. There is however, no similarly well-known case of a patient with a deficit in discourse processing abilities. One reason for this lack may be the difficulty in defining what is meant by a discourse processing deficit. Another reason for the lack of reports on patients with a discourse-processing deficit is that many patients with such deficits are either still able to function well in everyday life or they also have severe deficits at lower levels of language processing. Both circumstances would make the deficit less apparent to clinicians. In recent years, however, more sensitive neuropsychological investigations have detected impaired discourse functioning at several levels and have found such impairments to be correlated with right hemisphere damage. Unlike the situation with Broca's and Wernicke's patients, consistent focal lesions have not been found in these discourse aphasics. Various patients have lesions in right hemisphere homologues of Broca's area (e.g., the inferior frontal gyrus), Wernicke's area (e.g., posterior-superior and middle temporal gyrus) as well as the right hemisphere angular gyrus, dorsolateral prefrontal cortex and the medial frontal gyrus. Additionally, several other populations, such as individuals with autism (Dennis, 2001) and Alzheimer's patients (Papagno, 2001), with non-focal lesions or no lesions at all have difficulty with discourse processing. Thus, unlike the case for lower-level language processing research, neuropsychological studies of discourse processing in brain-damaged and other special populations did not provide much information about brain function other than a generalized notion that the right hemisphere was somehow involved in discourse processing.

It was not until the late 1980's that researchers began using brain imaging as a technique to investigate cognitive process. At the time neuroimaging was primarily based on Positron Emission Tomography (PET). One of the earliest neuroimaging investigations of a "discourse variable" was a PET study of metaphor comprehension conducted by Bottini et al., (1994). Subjects listened to either literal or metaphorical sentences, including such examples as:

plausible: *"The investors were squirrels collecting nuts"*
implausible: *"The investors were trams."*

The sentences containing metaphors elicited more activation in the right hemisphere, particularly the right inferior frontal gyrus and right posterior temporal cortex. The increased involvement of the right hemisphere may have been the result of an inference process that combined world knowledge with the contents of the sentence to resolve the ambiguity. This early finding of right hemisphere involvement in metaphor comprehension, combined with neuropsychological and visual field presentation data, contributed to the hypothesis that the right hemisphere is critically involved in metaphor comprehension and in other facets of discourse processing. This view is still widely held today although much refined. The right hemisphere coarse-coding hypothesis for example (described more

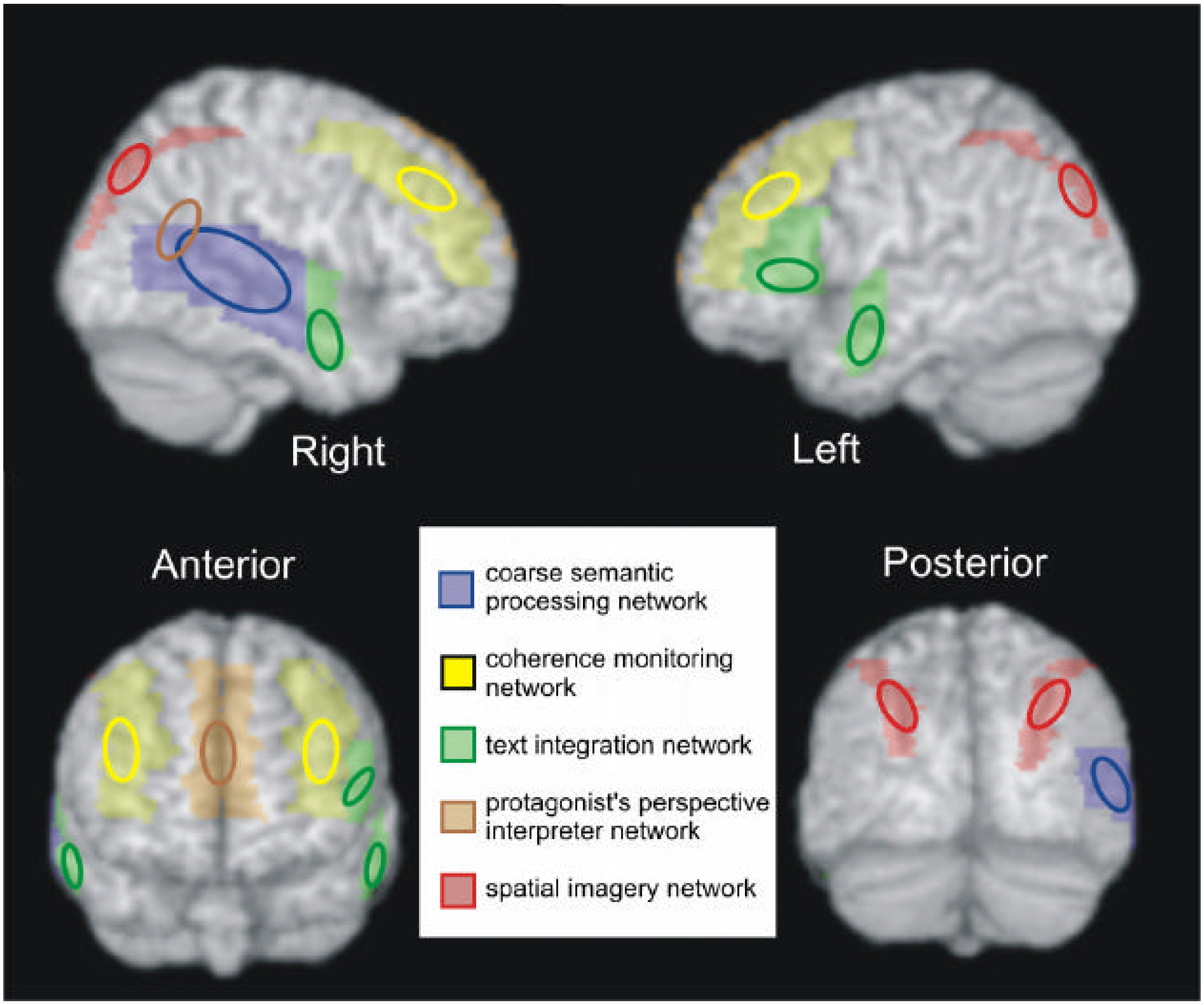

Figure 1. A Schematic representation of the Parallel Networks of Discourse. Shaded regions represent surface rendered anatomical regions as described in the text. A rough localization within anatomical regions are represented by colored ellipses.

fully in the lateralization section) developed by Beeman and colleagues (Beeman, 1993; Beeman, 1998; Beeman et al., 1994; Brownell et al., 1986) is a broader theory which encompasses the right hemisphere discourse view.

Nichelli, et al. (1995) was among the first to visually present passages consisting of multiple sentences (Aesop's Fables) passages in a neuroimaging study. (Another early auditory study was reported by Mazoyer et al., 1993.) Participants in Nichelli's PET study were asked to monitor either semantic details, syntactic details or the moral of the fable. Nichelli et al. concluded that the extra activation observed in the right hemisphere during moral monitoring and not in the other conditions was due to the drawing of an inference about the passage. Although there may have been some alternative accounts offered for this finding, this early text comprehension study advanced the view that there was something special about the role of the right hemisphere in discourse processing. In the decade since these early discourse studies, considerable advancement has been made in both methods and theory.

There were several possible reasons for the scarcity of neuroimaging research at the discourse processing level, some of which remain as problems: (1) neuroimaging research into language processing at any level is fairly new, (2) discourse processing is a broad field without a tradition for concern about neural mechanisms, (3) many of the key research questions that have been asked in the discourse processing area are not easily addressed with neuroimaging (due to the sluggish nature of the hemodynamic response and the low temporal sampling rate), (4) several of the frequently-used paradigms used to investigate discourse processing are not easily adaptable to the scanner environment (e.g., talk aloud protocols, naming), and (5) neuropsychological research on discourse processing deficits is limited. Recent advancements in technology and knowledge about cortical function have alleviated many of these constraining factors. The release of some of these constraints has opened many exciting new possibilities for the investigation of the neural substrate underlying discourse processing.

Specialized imaging paradigms for discourse processing research

Perhaps the largest factor constraining discourse imaging research is the challenge of developing appropriate experimental paradigms within the constraints of brain scanning methodology. A brief consideration of imaging methodology will make this point more clear. Imaging of brain activity using PET (Positron Emission Tomography) requires uptake of a tracer substance into the blood stream and into the brain during task performance. The relative insensitivity to the tracer requires long sampling intervals, such that brain activity can be measured only over many tens of seconds. As a result, PET studies have to utilize a "blocked" or "epoch" design in which many trials or items of the same type (i.e. constituting the same experimental condition) are presented in a sequence or "block," and brain activity is measured during the processing of the entire block of stimuli. The activity is then contrasted with other blocks (experimental conditions) in which a different set of processes occur. The activity in the experimental conditions is typically estimated with respect to a baseline task, usually a simpler task that is believed to be common to the two or more experimental conditions. The resulting image is then "subtracted" from the experimental blocks so that the non-baseline processing can be isolated. Even with some shortcomings of the subtraction paradigm (Newman et al., 2001) this methodology was very fruitful for the early days of imaging. At the very least it served to illuminate the extent of various networks engaged in many cognitive processes. But the nature of PET imaging led to some concessions in experimental design. Because PET is less sensitive and requires a radioactive tracer, most mainstream functional neuroimaging has turned to functional Magnetic Resonance Imaging, or fMRI.

The underlying assumption of fMRI is that it is a measure of neuronal activity, which should increase in some area when a cognitive process makes use of substrate in that area. This increase in neuronal activity results in an increase in local blood flow and volume. The oxygen content is then elevated in cortical areas which are being used. This will result in an increase in the MR signal, which is affected by the ratio of deoxygenated hemoglobin to oxygenated hemoglobin (Cohen & Bookheimer 1994).

A key advantage of the fMRI methodology is that a significantly smaller temporal window can be used in the measurement of brain activity than had been possible with PET. In some cases, the cognitive processing that we would like to measure is very short in duration and, particularly with language processing, it occurs on the order of tens of milliseconds. There is obvious difficulty when trying to measure a rapid cognitive process with a very slow measurement such as PET. In fact, PET doesn't really allow a consideration of the moment by moment changes in activation. It results in a single average image from a large temporal window. fMRI can be used to acquire an image in many consecutive temporal windows. The exact temporal window (termed TR, for "time for repetition") is related to the strength of the magnet, the amount of cortex being imaged, the criteria for signal to noise and, critically, the amount of time in which it takes the protons in the imaged substance to return to baseline after the introduction of a radio frequency pulse that causes them to tilt. Even though the temporal window in imaging varies across experiments, the range is roughly between 1 second (e.g., Just et al., 2004; Mason, et al., 2003) and 3 seconds (e.g., Martin and Weisberg, 2003; Robertson, et al. 2000; St. George et al., 1999).

Although early fMRI studies of discourse comprehension used a block design, they took advantage of the more rapid temporal window and the ability to compare conditions without subtracting out lower levels of cognitive processing. For example, Robertson et al. (2000) presented readers with blocks of sentences which either contained an indefinite article or a definite article. They found greater right hemisphere activation for the lists of sentences that used definite articles rather than indefinite articles. The definite article sentences were assumed to lead to more coherent discourse than the indefinite article sentences. They concluded that the additional right hemisphere activation reflected processes used to anaphorically relate the nouns in a text. Ferstl and von Cramon (2001) compared pairs of sentences that were coherent or incoherent as well as cohesive or incohesive. The coherence manipulation resulted in activation in the left frontal gyrus. The cohesion manipulation involved adding lexical connectives to the pairs of sentences to make them easier to understand as a single unit. Unlike Robertson et al. they did not find any additional right hemisphere activation. In both the Robertson et al. and Ferstl and von Cramon studies, the researcher utilized sentences or pairs of sentences in which a similar type of discourse level processing could be assumed to occur in all items of one type and not the items of another type.

Recently the development of slow-paced event-related fMRI has enabled the randomization of items within experiments (Buckner, 1996), and more importantly, has enabled the measurement of brain activity during the comprehension of individual sentences. In a slow-paced event-related fMRI, a blank interval appears (about 7 to 14 seconds, hence the term slow-paced) between the items, sufficient to allow the hemodynamic response to return to a baseline level (Mason, et al., 2003, Mason & Just, 2004) so that the activations associated with individual sentences are separable. The development of the slow-paced and fast-paced event-related experimental designs for fMRI allowed for imaging researchers to both randomize presentation of items as well as isolate specific cognitive processing to single sentences as opposed to examining gross levels of processing differences.

The Mason and Just study (2004) provides an example of how the event-related approach can be used to both randomize items as well as isolate specific types of cognitive processing. The study examined causal inferencing in the comprehension of two-sentence passages, drawn from previous stimulus materials (Keenan, Baillet, & Brown, 1984; Myers, Shinjo, & Duffy, 1987). The critical sentence in each passage was the second one, and the experimental manipulation was the degree of causal relatedness to the preceding sentence. The second sentence was followed by a fixation point so that the activation could return to baseline before the next passage. Using this technique, it was possible to identify the time interval of cortical activation that corresponded to the processing of the critical sentence. The processing was expected to differ among the experimental conditions, and this expectation was confirmed, as described later in the chapter.

Even the relatively rapid 1 second temporal sampling rate used by Mason et al. (2003) seems slow relative to the time measures and effect sizes that are typical of behavioral studies of discourse comprehension. For example, the reading time difference between reading a sentence with an indefinite article and the definite article may be only a matter of tens of milliseconds. Nevertheless, even small differences in processing time can produce measurable differences in the brain activity that has been aggregated over one or more seconds, as several studies (e.g., Robertson et al., 2000) have shown. Although averaging over 1 or more sec can be viewed as a weakness of fMRI, there is a sense in which it conveys an advantage, because it is often difficult to isolate the cognitive process of interest to a specific temporal window during the reading of a passage. For example, McKoon and Ratcliff (1986, 1989, & 1992) have shown that predictive inferences could be drawn either on the first sentence at which it was possible to draw the inference or in the subsequent sentence. Consider how Robertson, et al., (2000), Ferstl and von Cramon (2001), and Mason and Just (2004) dealt with this issue. In all three cases, they used well constrained materials of either a single sentence or sentence pairs to maximize the probability that the effect would occur in a specific temporal window.

In modern discourse research, the trend has been towards much longer and more naturalistic passages. This creates an added methodological burden. Every second of an imaging session is precious, because a participant will lie still for only so long. Although the background and introductory sections of these longer, naturalistic passages are critical, the expectation is that cognitive processing during this context-setting period is similar across conditions. The data acquired during this temporal window would either have to be discarded or treated as an additional factor in the design. Similarly, if the critical sentence does not include the expected cortical processing (perhaps the processing is delayed to a post-target sentence) then the likelihood of finding cortical evidence of a cognitive process is greatly reduced given that often there are as few as ten to twenty items per condition in neuroimaging experiments.

Perhaps the largest advantage that imaging research has over behavioral research is that it provides a fairly direct measure of the processing activity in each of the neural networks underpinning discourse comprehension. Measuring cognitive workload in most purely behavioral studies is difficult, frequently necessitating the use of secondary tasks as means of measuring processing load. fMRI studies allow the collection of button pressing data and response times, but many other data collection methods are problematic. Vocalization responses such as naming times and talk-aloud protocols are more difficult to acquire. Although, noise-canceling technologies have facilitated the extraction of voice responses in the noisy scanning environment, the head motion induced by jaw movements can render data unusable. The normal scanning procedure also makes it difficult to collect discourse recall data from a scanning session. As with voice responses, these problems can be overcome with some effort, but the problems have not been systematically solved so far.

In summary, brain imaging methodology imposes some constraints on discourse processing experimental design. Passages must be designed carefully to maximize the chance of finding how a complex cortical network functions in discourse comprehension. Specific process must be temporally localized to a specific point in the text. Moreover, the same process must occur across the majority of passages for the majority of subjects. For example, if the generation of a bridging inference is being examined, the inference must be generated at a similar point within the text across stimuli and across readers to be measured. The limitation on number of passages and subjects constrains the ability to average over a large set of passages.

Even with the constraints on experimental design, imaging still has the benefit of examining how the network as a whole functions. This is true even in those cases in which a process, such as inferencing, might not occur at a specific temporal point. Thus, it is possible to see the cognitive workload required for generating an inference with imaging even if it cannot be determined behaviorally whether or when an inference was drawn. fMRI can thus be sensitive to processes that have only small effects on behavioral measures, while at the same time capturing the qualitative variation and parallel nature of the processes underlying discourse comprehension to which response times are insensitive.

New Perspectives on Text Integration

Text attributes at the discourse level enter into combinations with other information to allow a reader to weave individual sentences into an integrated narrative structure. The resulting conceptual structure incorporates pragmatic information and connects the text with the reader's world knowledge. This discourse process extends beyond strictly linguistic information. For example, discourse comprehension requires that the reader generate inferences and extract meaning that is not explicitly encoded in the text. Readers must make inferences in order to integrate sentences in a coherent fashion, filling in what is absent from or ambiguous in the text. Several researchers have tried to describe the properties of the internal representation of discourse. One of the most influential was the situation model as developed by van Dijk and Kintsch (1983). The situation model arises from linguistic processing of the text itself (lexical access, syntactic processing, and construction of a propositional based micro-structure) and an interaction with non-linguistic cognitive processes. The situation model is a result of this interaction created by connecting the text with knowledge derived from the reader's long-term memory, and involves additional demands upon attention (e.g., the ability to shift points of view and parse sequences of events), working memory (the ability to retain longer term, anaphoric references), and the contribution of visual imagery, empathy, and emotional knowledge.

Some early attempts at imaging investigation of discourse processing were designed to determine the neural underpinnings of the construction of a situation model. An fMRI study conducted by St. George and colleagues (1999) presented syntactically well-structured paragraphs which were uninterpretable by virtue of never specifying the referent of the text. The paragraphs were similar to those previously used by Bransford and Johnson (1972.) These paragraphs were either preceded or not preceded by a title that disclosed the referent. For example, these paragraphs contained sentences such as "Typically, success requires that you start with your left leg, and make sure that it is securely in place. Then swing your body high into the air." Without knowledge of the referent, it is difficult if not impossible to understand the passage. But with foreknowledge provided by a title ("Riding a horse") all of the sentences become interpretable.

The fMRI results revealed that the left hemisphere, as a whole, exhibited no effect of whether the paragraph was presented along with the title, while the right hemisphere revealed significantly greater involvement during the presentation of the untitled paragraphs. More specifically, the left middle and superior temporal sulci became more active during the processing of the titled paragraphs, and conversely, the right middle and superior temporal sulci became more active during the processing of the untitled paragraphs. These results support the idea that the right hemisphere is concerned with the mapping of information into a text representation, as discussed below. In addition, these results suggest that the processing roles of the two hemispheres are, in fact, distinguishable.

Tomitch et al. (2004) attempted to investigate the differential processing of the left and right hemisphere during text integration using fMRI. They manipulated the serial position of the topic sentence in short, three-sentence paragraphs. The topic sentence contained a unifying super-ordinate theme, while the supporting sentences in the paragraph instantiated that thematic concept. The serial position manipulation consisted of varying the position of the topic sentence in the paragraph, placing it either in the first position - *topic 1st* or in the third position- *topic last*, as shown below.

'Topic first' condition

> *This is a totally guaranteed method to completely eliminate a flea infestation on your dog or around his doghouse. (Topic first)*
>
> *First, late in the evening, chain your dog to his doghouse, build a small bonfire and let it burn overnight. (Support 2nd - #1)*
>
> *They are insatiably attracted to heat, become enamored of the fire, leave your dog, jump into the flames, and die. (Support 2nd- #2)*
>
> *Fleas will be eliminated from your dog or his doghouse with the use of a bonfire. True or false?*

'Topic last' condition

> *First, late in the evening, chain your dog to his doghouse, build a small bonfire and let it burn overnight. (Support 1st - #1)*
>
> *They are insatiably attracted to heat, become enamored of the fire, leave your dog, jump into the flames, and die. (Support 1st - #2)*
>
> *This is a totally guaranteed method to completely eliminate a flea infestation on your dog or around his doghouse. (Topic last)*
>
> *Fleas will be eliminated from your dog or his doghouse with the use of a bonfire. True or false?*

This paradigm made it possible to measure the brain activation associated with the comprehension of each of the three sentences in each paragraph separately. The results revealed differential effects in the two hemispheres. The right temporal cortex revealed greater involvement during the processing of topic sentences, regardless of their location within the paragraph. In contrast, the left temporal cortex was sensitive to the location of the topic sentence.

Tomitch et al. cited Gernsbacher's (1990) *Structure Building Framework* (SBF) to account for the processing underlying the cortical activation. According to SBF, discourse comprehension builds cohesive mental representations using three general processes: laying the foundation, mapping incoming information to previous information, and initiating a new substructure if the incoming information is not adequately coherent with previous information. SBF states that the first step in building a mental representation of the text is to lay a foundation to which subsequent information presented in the text can be attached. Presumably this first stage must occur across all passages regardless of the order of the topic sentence; the consistent left temporal activation on the first sentence suggests that the left temporal region is involved in laying the foundation of the text representation.

A second prediction SBF makes is based on more involvement of the "shifting" process in paragraphs whose topic sentence is in the final position. When the topic sentence in the final position, increased shifting is, therefore, expected to result in higher activation levels. This response was also observed in the left temporal region.

The right temporal region was sensitive to the presence of a topic sentence but not to its location. This suggests that the right temporal region 1) is sensitive to whether a sentence is a potential statement of the topic and 2) performs additional processing on the potential topic sentence. The right hemisphere may then be responsible for using the information forwarded by the left to "fill in" or map information onto the text representation built by the left and to connect it with the participant's world knowledge. This right temporal activation "mapping" activation was also found by Robertson et al. (2000) for both indefinite and definite articles; in contrast, the less coherent, indefinite article texts also resulted in additional right frontal activation than the definite article texts.

Several other cortical regions have been found to play a role in tasks that require structure building. Partiot et al. (1996) investigated script processing and found bilateral precuneus/posterior cingulate regions to be activated, along with bilateral medial parietal cortex, during processing of event sequences. Maguire et al. (1999), using Bransford and Johnson (1972) passages with or without titles, also found these same areas to be active in linking textual information with subjects' prior knowledge. These operations must be central to construction of a situation model, connecting the narrative text with knowledge about the real world.

Narrative-specific activations have also been found in the temporo-parieto-occipital junction, angular gyrus, and superior temporal sulcus. A prevailing view has been that the angular gyrus plays a key role in grapheme to phoneme translation. But this region is in fact multifunctional, and has been implicated in a variety of cognitive processes—attention, semantic association, problem solving, and mental imagery (Cabeza and Nyberg, 2000) that are likely to be engaged in the narrative context. For example, the angular gyrus is activated when subjects visualize a scene derived from a written text (Mellet et al., 2002)—precisely the sort of mental model representation required during narrative processing.

Recently, Ferstl, Rinck and von Cramon (2005) examined passages in which the reader might encounter inconsistent emotional or temporal information in a passage. They suggested the contrast of consistent and inconsistent information that should be coded at the situation model level would allow them to examine cortical networks specialized for situational level text representation. They concluded that activation in the frontal cortex indicated a specialization for building and maintaining a situation model representation. The specific region within the frontomedial cortex varied as a function of the type of information and whether it was involved in noticing or resolving the inconsistency. First, the ventral portion of the medial frontal cortex was involved in detecting inconsistent emotional information. In contrast, the dorsomedial frontal cortex was active in the processing of emotional consistencies suggesting that a protagonist interpreter network was engaged during the attempted resolution of the inconsistent information. The chronological inconsistency activation was located much more anteriorly in the orbital portion of IFG and the frontopolar region. Interestingly, the right anterior temporal lobe was more active during the processing of inconsistent texts regardless of the text type, suggesting that as text processing became more difficult, the specialized text integration network spilled over into the right hemisphere.

To summarize, while there is still a significant amount of research to be done to clarify the contributions of the left and right hemisphere in text integration, neuroimaging studies such as those outlined here are making good progress. Although it must be true that the two hemispheres work together to accomplish such a complex function as comprehension, it does appear as though they are involved in different aspects of discourse processing. It seems as though the identification of the main idea and the building of the text representation is separable from the mapping of that information onto the discourse structure with both hemispheres working in an interactive manner in order to construct a coherent representation of the text. Furthermore, the type of the information within the text plays a role in which areas are responsible for building and maintaining a representation of the text. Propositional level information may be processed by left frontal and left temporal areas as long as resources are available. Situational model information results in an engagement of the medial frontal cortex. Specific areas within the cortex may be dependent upon the nature of the input, for example, emotional information related to protagonist interpreter should activate more dorsal frontal regions.

New Perspectives on Inference Processing

Often, the links between events in a story are not explicitly expressed and the reader must connect them by generating linking inferences and integrating them with the presented information. Almost every text requires a reader to draw on a rich store of shared knowledge about the world. There is a strong relation between inference generation and text integration. Inference generation is often necessary in building accurate text representations and conversely, an accurate text representation is often necessary for inference generation.

Inferences may be drawn to fill in missing information, resolve discrepancies or to predict yet unmentioned events or facts. There are several types of inferences, including coherence, predictive, elaborative, and causal. The classification of various types of inferences has been a continuing topic in discourse research and there have been several excellent attempts to resolve this classification problem (e.g. Singer, 1994; van den Broek, 1994).

A successful inference generally occurs as a result of generating a possible inference and then integrating that inference into the internal representation of the text. The Construction-Integration (CI) model of text comprehension (Kintsch, 1988) is consistent with this general description of inferencing. According to the CI model, there is a first process in which the many possible inferences are liberally generated (inference construction), followed by a second process of integrating only those inferences that have a high degree of connection with the reader's representation of the preceding text (integration). A successful integration of an inference results in a representation of the text that involves both the specific propositions contained in the text and those propositions that were generated by the reader to connect information in the text.

Patients with lesions to the right hemisphere generally have trouble drawing inferences in order to integrate sentences and maintain coherence (Beeman, 1993; Brownell et al., 1986). These patients are less likely to mistakenly false alarm to inferences in a text recognition task, presumably because they never generated the inferences in the first place (Grafman et al., 1987). Such patients also make elaborative inferences more easily than bridging inferences (Tompkins and Mateer, 1985). Furthermore, Beeman and colleagues (1994) have shown that when probes are inference-related, they are primed in the left visual field-Right Hemisphere immediately, and are primed in both left visual field-Right Hemisphere and right visual field-Left Hemisphere at a later time. This finding suggests that the right hemisphere is particularly involved in inference processing.

There have been few neuroimaging studies of inference processing. One question that has been debated is whether logic-based inferencing relies on the same processes as text-based inferencing. In an fMRI study, Caplan and Dapretto (2001) directly addressed this issue by comparing the generation of logic-related inferences versus text-based inferences. There were two types of sentence pairs as shown below

Text based: *"Do you believe in angels?"*
"Yes, I have my own special angel"

Logic-related: *"Do you like having fun?"*
"Yes, because it makes me happy"

While the logic condition produced greater activation within the left language areas, the text-based condition revealed more activation in the right hemisphere. This study is significant in that it suggests that at the neural level, and consequently at the process level, there are significant differences between logic-based and text-based inferencing. Also, the results converge with the neuropsychological findings showing that the right hemisphere is intimately involved in text-related inference processing.

Mason and Just (2004) reported an fMRI experiment that was designed to examine the cortical areas that are involved in making causal inferences during reading. Participants read sentence pairs that varied in terms of their causal relatedness. For example, an "outcome" sentence (e.g., *The next day his body was covered with bruises.*) was preceded by one of three sentences (equated for overall length and number of propositions) that described an antecedent condition:

Highly Related: *Joey's big brother punched him again and again.*

Moderately Related: *Joey's crazy mother became furiously angry with him.*

Distantly Related: *Joey went to a neighbor's house to play.*

In previous behavioral studies using similar materials, Keenan, Baillet, and Brown (1984) and Myers, Shinjo, and Duffy (1987) found that reading times on the sentences increased as the degree of relatedness between the sentences decreased; that is, the reading times increased from the highly- to moderately- to distantly-related conditions. Paradoxically, however, the participants' memory for the two-sentence passages (as measured using a variety of recall and recognition tests) followed an inverted U-shaped function; that is, the sentences in the moderately-related condition were remembered better than those in both the highly- and distantly-related conditions. Thus, the participants' memory for the sentences does not seem to be a simple monotonic function of either their reading times or the degree of causal relatedness between the two sentences being read.

In the fMRI study of causal relatedness, Mason and Just (2004) found three main foci of fMRI-measured cortical activation among the language areas. In the left hemisphere language areas, the activation volume did not vary across the three relatedness conditions. In contrast, the activation volume in the bilateral dorsolateral prefrontal cortices showed a marked (albeit not statistically reliable) increase as the sentences became less causally related. Finally, the most interesting pattern of activation volume was observed in the right hemisphere homologues of the language areas: the activation volume was consistent with the patterns that had been reported with recognition and recall measures.

To account for their fMRI data, Mason and Just (2004) proposed that two different cortical networks support the generation and the integration of inferences during reading. The first network, consisting of the left and right dorsolateral prefrontal cortex is more involved in generating the inferences. As the causal distance between two sentences increases, the dorsolateral prefrontal regions generate more inferences, leading to an increased volume of activation. The second network, consisting of the right inferior frontal gyrus, right superior and middle temporal gyri, and right inferior parietal lobe, is more involved in integrating the possible inferences that have been generated. Because of the relative differences in integrating the inferences in the three conditions, the volume of cortical activation that was observed in this region is described by an inverted U-shaped function, with more activation occurring with the moderately related than either the highly-related or distantly-related sentences.

Reichle & Mason (in press) present a working memory account for the additional right hemisphere activation that occurs as a result of generating an inference in the moderately related condition. They suggest that, as proposed by Just et al. (1996), there is an inherent limit on how much cognitive processing can be done per unit of time in left hemisphere language areas. In the context of text processing, this limit means that to the degree that working memory resources are being used to process the text and generate inferences, those resources will not be available for integrating those inferences into long-term memory. Reichle and Mason propose a computational model to demonstrate that these resources are exceeded only in the moderately related condition, such that the remaining processing load that cannot be accommodated in the left hemisphere spills over into the right hemisphere.

Research is only now beginning to map out the cortical network associated with drawing inferences in reading. Evidence to date suggests that the right hemisphere plays a key role in such a process (Beeman, et al., 1994; Mason & Just 2004). At this point, at least three plausible theories have been developed to illuminate the right hemisphere's role. Reichle and Mason (in press) building on work by Just et al. propose that a limited capacity is exceeded across inferencing component processes. This then leads to processing being passed to the right hemisphere. This is in contrast to an account proposed by Mason et al.; they propose that the right hemisphere is utilized during the integration of an inference and that inferences are generated by utilizing the dorsolateral prefrontal cortex. Finally, Beeman's coarse coding theory leads to the prediction that inferences are accomplished as the result of activation of coarsely coded semantic information in the right hemisphere. In this account, it is not the inference per se that is processed in the right hemisphere but rather the information from which the inference is developed. A further account combines aspects of these previous explanations. Inference generation is supported by the right hemisphere coarse semantic network. Additional attempts to utilize this network will be signaled by the dorsolateral prefrontal coherence monitor, provided resources are available. As the propositionalization work of the left anterior temporal text integration network becomes more demanding (and resources are consumed), this processing will spillover into the right anterior temporal region. It is clear that further research will be needed to specify at which level of difficulty each of the networks are engaged for various readers' abilities.

New Perspectives on Figurative Language Processing

The study of metaphor comprehension has long been a major area of interest in behavioral studies of figurative language (e.g., Allbritton, McKoon & Gerrig, 1995; Gerrig & Healy, 1983; Gibbs; 1990). With the development of recent theories and methods that illuminate the role of the right hemisphere in discourse processing (see Beeman & Chiarello, 1998 for an extensive listing), the right hemisphere's role in metaphor comprehension arises as a central issue. As mentioned previously, the study of the neural basis of metaphor processing has some neuroimaging precedent. Bottini et al., (1994) showed that the processing of novel metaphors resulted in an increase in right hemisphere activation. The finding from this early PET study was one of the reasons that metaphor processing has been recently described as a right-hemisphere language function. In fact, Beeman (1998) listed metaphor processing as one of the functions for which the right hemisphere is well suited. However, that is turning out to be too simple a view of a complex process.

A recent brain imaging study conducted in our laboratory indicated that the comprehension of frozen metaphors activated the same left hemisphere language areas that were active in the processing of literal sentences, with the activation being more extensive for the frozen metaphors in the left inferior frontal gyrus (Eviatar & Just, under review). Unlike the results of Bottini et al. which used novel metaphors, (1994) the frozen metaphors in the more recent study did not activate the right hemisphere posterior superior temporal areas more than literal passages. Eviatar and Just concluded that the processing of frozen metaphors required semantic selection of a more abstract meaning associated with the figurative phrase. In the case of frozen metaphors, these frequently used abstract meanings are lexicalized. Further, they proposed that the comprehension of such a metaphor would require selection of appropriate aspects of the meaning and suppression of the inappropriate, or literal, meaning (Gernsbacher & Robertson, 1999). It is presumably for this reason that additional activation was observed in the left inferior frontal gyrus, an area associated with the selection and suppression of lexical content (Thompson-Schill, 2003; Keller et al., 2001). Rapp et al. (2004) also examined novel metaphors in simple "An A is a B" sentence frames. They asked their participants to judge whether their metaphors had a positive or negative connotation. Even though they used novel metaphors, Rapp et al. found higher activation for metaphoric versus literal sentences in left inferior frontal gyrus and left inferior temporal gyrus but not in the right hemisphere. There were several differences between the Rapp et al. and Bottini et al. studies, but the largest may have been inconsistencies in syntax of the Bottini et al. materials. Although many of Bottini et al.'s metaphors were of the "A is a B" variety, a large number of them were presented in more complex syntax such as "The old man had a head full of dead leaves." Rapp et al.'s lack of finding a right hemisphere effect in metaphor comprehension may have arisen due to the fact that a broader situation model did not have to be constructed to understand the metaphor in isolation. The simple metaphors only require an equation of two concepts without discourse or even syntactic processing.

Mason, Eviatar and Just (under review), in order to reconcile the Bottini et al novel metaphor result and the Eviatar and Just frozen metaphor results, contrasted cognitive processing during the reading of literal sentences with two different types of figurative language: novel metaphors that are created de novo, and frozen metaphors, which have been previously encountered and may have a stored representation. The stories contained three sentences. The first two sentences were presented simultaneously, and constituted the context for the third sentence, which was always a statement uttered by one of the characters. The character's utterance always contained either a frozen metaphor, novel metaphor or a literal phrase.

Frozen Metaphor:
Mary got straight A's on her report card.
Her parents were proud of her.
They said, "You are as sharp as a razor."

Novel Metaphor:
It was Judy's first time on an airplane.
Her mom let her have the window seat.
Judy said "We're surrounded by great white mushrooms."

Literal:
Johnny went on a hike with his brother.
Suddenly he saw a huge snake next to his foot.
He said, "I have always been afraid of snakes."

As in the Eviatar and Just results, Mason et al. found that when reading a frozen metaphor passages, the same language processing areas are active that are active during normal reading (e.g., DLPFC bilaterally, left middle and superior temporal lobe as well as left inferior frontal gyrus). In addition to the shared language processing areas, we found additional activation for frozen metaphors in right middle and superior temporal lobe and superior medial frontal gyrus and the paracingulate area. But the full story was much more complex and interesting. The novel metaphors resulted in primarily visual-spatial activation, suggesting that visual imagery processes were being used to instantiate and/or interpret the novel metaphors used in the study. In contrast, the frozen metaphors were associated with activation in a superior-medial frontal cortex. This is the same region as the proposed protagonist interpreter network and has often been associated with theory of mind processing, and indeed, the frozen metaphor passages tended to refer to a character's traits (e.g., "You are as sharp as a razor."). These results demonstrate a consistently emerging pattern in discourse processing research; during discourse processing, a complex set of cortical networks are dynamically recruited depending on qualities of the text and the reader's goals.

The few studies conducted on figurative language suggest that processing of metaphors within text utilizes the same cortical regions as do several other discourse tasks. In particular, trying to understand a metaphor has resulted in engagement of right hemisphere regions (Bottini, et al., 1994; Mason, Eviatar & Just, under review) as well as increased processing in the left inferior frontal gyrus and left temporal regions (Bottini, et al., 1994; Eviatar & Just, under review; Mason, Eviatar & Just, under review; Rapp, et al., 2004). Recently, Mashal, et al. (2005) also found a selective right hemisphere involvement in the processing of novel metaphors and a left hemisphere involvement in the processing of conventional metaphors. Specific types of metaphors also seem to activate a region in or near the medial frontal gyrus (Mason, Eviatar & Just, under review). As mentioned in the previous section, this frontal region was also active during the processing of inconsistent emotional information (Ferstl et al., 2005). Mason et al. suggested that their frozen metaphors activated this region in part because the frozen metaphors they used were rated as high on an emotional content scale. Together these results indicate that, much like the case with other discourse tasks, text variables must be carefully controlled in experiments investigating figurative processing.

Coulson & Van Petten (2002) propose that conceptual integration results from a process of *alignment* (Gentner & Wolff, 1997) or *mapping* in conceptual blending theory (Coulson, 2000). Conceptual blending theory involves the establishment of a blended space into which concepts and relations from both the literal concepts and the target metaphoric concepts are imported. The blended space can then be combined with background knowledge so as to understand the metaphor. As suggested by Coulson & Van Petten (2002), a blended space may be necessary to understand metaphors. It is possible that this blended space may be no different than an episodic-based situation model. The additional processing required to either maintain two mental models (the literal and the figurative) in parallel or the need to combine and supplement the model with information from background knowledge may account for the observed increase in cortical activation in response to reading a metaphor. In the case of novel, discourse based metaphors, the additional right hemisphere activation may be a spillover of processing from the text integration area. In this case the interpretation of a situational model metaphor will be similar to a complex inference. Furthermore, other areas that become active in metaphor processing will be a function of the text. Metaphors require interpreting the perspective of the protagonist may be accompanied by an increase in activation of the medial frontal protagonist interpreter network. The reason for the recruitment of specific areas is still partially speculative at this point. Future research in this area will be necessary to determine how much of the right temporal activation and the medial frontal activation are due to figurative language processing per se, and how much is simply a result of text factors.

New Perspectives on Lateralization

The classical view, derived in 19th century clinical studies of aphasia, held that the left hemisphere is dominant for both comprehension and production of language. It is now clear that the right hemisphere plays a role in language processing as well (Gardner et al., 1973) supporting semantic operations (Koivisto, 1998) particularly global processes like inference, coherence, conceptual association, text integration (St George et al., 1999) and prosody (Hesling et al. 2005; Plante et al., 2002). Right hemisphere involvement during narrative processing has been noted in several neuroimaging studies, both for comprehension (Bottini et al., 1994; Mazoyer et al., 1993; Nichelli et al., 1995; St George et al., 1999) and production (Braun et al., 2001). The right hemisphere involvement may reflect coherence and inference-related processes at the discourse level, such as when readers make connections between sentences, integrating these into a global representation, processing metaphors, and otherwise utilizing information not encoded in the text.

In addition to the neuroimaging data, there is clear evidence of a right hemisphere role in discourse comprehension from neuropsychological data. For example, patients with right-hemisphere damage have difficulty connecting and integrating semantically distant concepts (Brownell and Martino, 1998; Beeman, 1993; Birhle et al., 1986; Brownell et al., 1983). However, patient studies have failed to reach a clear conclusion regarding the contribution of the right hemisphere homologues of Broca's and Wernicke's areas to discourse processing

Beeman's coarse coding hypothesis (Beeman, 1998) applied to language is an important theoretical contribution that relates the cognitive processing of discourse to its neural basis. The coarse coding hypothesis proposes that the two hemispheres differ in the level of granularity at which they code semantic information. Beeman proposes that the left hemisphere uses fine semantic coding to quickly select a small number of relevant meanings, whereas the right hemisphere uses a coarse semantic coding scheme in which it weakly activates a broad spectrum of meanings and features (Beeman, 1993; 1998).

According to the coarse coding hypothesis, word meanings are represented bilaterally. In the left hemisphere, word meanings are represented by localized semantic fields so that their core meanings can be rapidly and reliably accessed. In the right hemisphere, word meanings are represented by more distributed (and possibly overlapping) semantic fields. The coarse right hemisphere semantic field allows for more than one sense of a word's meaning to be accessed. These coarse semantic fields facilitate processing of figurative language and are particularly useful in solving insight problems.

Strong support for the right hemisphere based coarse coding hypothesis comes from priming studies in which the hemisphere to which words are passed is controlled via visual field presentation. For example, when processing ambiguous words, priming occurs for subordinate meanings of ambiguous words after 750 msecs when presented to the left visual field/right hemisphere (LVF/RH) but not in the RVF/LH (Burgess & Simpson, 1988). Additionally, several weakly associated words primes a concept word (e.g., *cry*, *foot*, and *glass* together prime *cut*) when the words are displayed to the left visual field/right hemisphere (LVF/RH), but not when the words are displayed to the RVF/LH (Beeman et al., 1994). Similarly, distantly related concepts prime each other (e.g., *deer* primes *pony*) over longer time intervals in the LVF/RH than in the RVF/LH (Beeman et al, 1994; Chiarello, Burgess, Richards, & Pollock, 1990; Nakagawa, 1991). Beeman suggests these results indicate that right hemisphere maintains less central aspects of a word's meaning and distant associates longer than the left hemisphere.

It is less clear how a representation based hypothesis, such as coarse coding is related to inference making. Here neuroimaging results provide a database on which theories of discourse processing can be constructed, possibly using the coarse coding hypothesis as a fundamental assumption. For example, the broadly distributed, partially overlapping semantic fields in the right hemisphere are ideally suited to allow the cortical activation from several distantly related and/or weakly activated concepts to accrue and converge, bridging whatever semantic information happens to be represented in the fields. One possibility is that the right hemisphere semantic network developed in parallel to the left hemisphere semantic network. Because the left hemisphere plays a role in phonological processing and the majority of language input during development is auditory, the left hemisphere may have developed a finer grained semantic representation system. The coarser semantic representation of the right hemisphere semantic network then becomes a strength for the system in the case of inferencing. In many cases, generating possible inferences requires connection of distant features of words or relations between concepts. The coarse representation in the right hemisphere more easily supports this type of connection.

While many neuroimaging studies of language have tended to support the traditional notion of strong left hemisphere lateralization, this may be due to the superimposition of meta-linguistic tasks in these studies. Long and Baynes (2002) proposed that although situation model processing involves an interaction with the right hemisphere, input from the left hemisphere is also required. It is therefore not surprising that even in discourse comprehension tasks, the left hemisphere remains highly active (Mason & Just, 2004). Not only does the left hemisphere remain active, but, as the results of many of the previously mentioned neuroimaging studies have shown, there is additional left hemisphere activation accompanying the right hemisphere activation (e.g., Xu et al., 2005).

Xu et al., (2005) showed that even at the single word level, text comprehension naturally engages both hemispheres (although in this context, responses are still markedly lateralized to the left). Right hemisphere activation becomes prominent when words are presented in a sentential context, and may reflect coherence and inference at the propositional level during which readers make connections within sentences to form coherent representations. But Xu et al. found that it was during the processing of narrative that right hemisphere activity was most robust. Reading of the narrative was associated with strong bilateral activations throughout the brain, encompassing perisylvian, extrasylvian, premotor cortices, and cerebellum, indicating that both linguistic and extralinguistic processes play a role in discourse comprehension.

Xu et al. (2005) developed a step-by-step account of how a set of brain structures, particularly the right hemisphere, functions during the reading of a narrative text. They analyzed their passages using the formal structural measures developed to determine the story grammar or structural regularities in the narrative content (Mandler and Johnson, 1977; van den Broek, 1994). On the basis that "text comprehension, as defined by Kintsch and Van Dijk (1978) must interact with formal structure: that is, since a mental model of the narrative is constructed in increments and adapted as a story unfolds, we reasoned that a reader's cognitive effort would change—that is, both language and language-related processes should be differentially engaged during the succession of narrative segments and should be reflected in dynamically fluctuating patterns of brain activity" (Xu et al., 2005, p.1013).

Another possible reason for the right hemisphere's involvement in discourse comprehension tasks comes from studies of syntactic processing. Just and colleagues (Just & Carpenter, 1992; Just, Carpenter, Keller, Eddy, & Thulborn, 1996; Reichle, Carpenter, & Just, 2000) have developed a theory in which there is an inherent limitation on how much cognitive processing can be done per unit of time. Just et al. (1996) have shown that the right hemisphere becomes active in sentence comprehension as the syntactic processing demands of the sentence increase. It may be the case that additional right hemisphere activation in discourse comprehension arises in response to the left hemisphere's capacity limitations. It is also important to note that the principle of working memory's limited capacity has been widely used in existing theories of text processing (Frank, Koppen, Noordman, & Vonk, 2003; Golden & Rumelhart, 1993; Goldman & Varma, 1995; Kintsch, 1988; Kintsch & van Dijk, 1978; Langston & Trabasso, 1999; Myers & O'Brien, 1998; Schmalhofer, McDaniel, & Keefe, 2002; van den Broek, Risden, Fletcher, & Thurlow, 1996; Tzeng, van den Broek, Kendeo, & Lee, 2005). Thus, in the example of inference processing, to the degree that the left hemisphere's working memory capacity is consumed by the processing of text and the generation of inferences, there may not be enough capacity left to integrate those inferences. As a result, inference processing may invoke right hemisphere processing.

Ferstl et al. (2005) specifically propose that the right anterior temporal activation they find with inconsistent situational model level information is a direct reflection of cross hemisphere spillover of processing. They suggest that propositionalization is a left anterior temporal specialization. When situational model information is inconsistent, the propositionalization of incoming text information is more difficult and it results in the engagement of the right anterior temporal lobe. It is likely that the activation of the right hemisphere in many inference tasks could be a result of both activation of coarse coded semantic information as well as spillover of situation level propositionalization. It remains to be seen if these two hypotheses can be separated.

One dominant point in the neuroimaging discourse research is that the right hemisphere plays a role in discourse comprehension. This has been seen in many of the experiments presented in this chapter. The coarse coding theory (Beeman, 1998) and the spillover of processing theory (Just et al., 1996) provide two recent accounts that attempt to provide a framework that allows for the right hemisphere homologues of Broca's and Wernicke's areas to become active in several different experimental manipulations. It is important to note that these frameworks are not intended to be in place of previous discourse theories (e.g. Kintsch, 1988; Kintsch & van Dijk, 1978) but rather to provide an explanation of underlying component processes present in these discourse theories. Moreover, they are also consistent with some attempts to tie internal representations of the discourse to specific regions, such as Grafman's script based Meaning-Knowledge-Units (Grafman, 1995), situation models (Ferstl et al., 2005; Schmalhofer, 2003), and a bilateral discourse model (Long & Baynes, 2002). This new perspective on lateralization enables us to propose that the right temporal lobe is involved in discourse processing in both a coarse semantic processing network as well as spillover of the left anterior temporal text integration network.

A New Component of Discourse Processing: Protagonist Interpreter

Narrative-specific activations have been consistently found in the medial frontal gyrus, and precuneus/posterior cingulate cortices (Ferstl and von Cramon, 2001, 2002; Ferstl, et al., 2005; Xu, et al, 2005). The medial frontal gyrus has been shown to play a role in theory of mind processes (Fletcher et al., 1995), defined as the capacity to intuit the beliefs, desires, and goals and predict the actions of others. An everyday understanding of others' minds is clearly necessary for interpreting the intentions, goals, and actions of characters within a narrative. This same area has also been found to be activated in the comprehension of metaphor (Bottini et al., 1994) and identification of thematic roles within a story (Nichelli et al., 1995). All of these are considered to be discourse level variables that are likely to be engaged during narrative comprehension.

This theory of mind network has been reported to be engaged in a range of cognitive functions that include 'mentalizing' (Castelli et al., 2002), that is, the ability to attribute mental states to others (essentially theory of mind), understanding social concepts (Martin and Weisberg, 2003) and making moral judgments (Greene et al., 2001; Moll et al., 2002) and on this basis it has been argued to play a central role in social cognition. Yet, as mentioned previously, this system has also been shown to participate in cognitive processes that lie outside of the social domain, from inferring logical relationships between events or propositions (Ferstl and von Cramon, 2002) to evaluating and verifying facts based on personal knowledge and experience (Zysset, et al., 2002).

Activation in this medial frontal area has also been found in tasks that involve emotional processing and more specifically, emotion related to memory (Canli, et al., 2002; Nakic & Gabrielli, unpublished manuscript). Activation in this area has also been found when participants had to integrate inconsistent emotional information in stories (Ferstl, et al. 2005). Thus the additional activation in medial frontal areas might be attributed to the activation associated with emotion-related processing. As previously mentioned, frozen metaphors that were high in emotionally based content also resulted in activation in the medial frontal gyrus (Mason, et al., under review).

This medial frontal area has also been shown to be active in a number of tasks that require representing the mental states of others, or Theory of Mind (Gallagher and Frith, 2003). Unlike the novel metaphors which require visualizing, frozen metaphors are much like ambiguous words and require abstraction. The ability to understand this type of abstraction requires that the reader be able to mentalize the characters' intentions and internal emotional state within the story.

The fact that the medial frontal region is often activated in discourse tasks, social cognitive processing, and theory of Mind suggests that this cortical area plays a general role that would be common in all of these tasks. Xu et al. (2005, p. 1012) suggest that the medial prefrontal cortex operates "at the interface between self and environment, yoking a variety of cognitive processes to knowledge about the world—a function that is clearly central to narrative comprehension." In this sense, processing language as discourse would be expected to engage systems that lie outside the language cortices.

The research demonstrating the activation of the medial frontal area in discourse processing shows just how powerful the neuroimaging approach is. Although, this area was found to be activated in many studies of discourse comprehension, it was not previously considered a language processing area. The medial frontal area has been more closely linked with the processing of information that required an ability to examine a situation from a different perspective (e.g., Castelli et al., 2002). It has also been found to be active in tasks that require an understanding of emotional and moral aspects of a situation (e.g., Greene et al., 2001). The recent discourse work has shown that this area activates during narrative text and becomes differentially active in response to a manipulation of character centered emotional variables within a text. However, activation of this region in non-discourse tasks (Krause, et al. 1999) as well as "inanimate" texts (Ferstl & von Cramon, 2002) indicates a domain general role. It seems evident that within narrative text, this domain general cortical region activates strongly in response to understanding protagonist oriented stimuli.

Outline of a Neurocognitive Account of Discourse Comprehension

Our goal here is to provide a theoretical framework based on the results reviewed in this chapter. Although this framework is predominantly based on neuroimaging results, it is intended to be consistent with discourse theories that have arisen from behavioral, neuropsychological, and neuroscience research. The purpose of this framework is to integrate these different research approaches and to extend current conceptualizations of discourse processing.

This framework is consistent with a more general approach in which it is assumed that the nature of the text and the goals of the reader affect the extent to which specific cortical regions are activated when reading. The potential exists for many different cortical networks to become active during reading; the theory should ultimately specify the conditions under which a particular network is engaged to make up the whole of the system.

Although the understanding of the complex nature of discourse processing at the cortical level is a lofty long-term goal, the outlines of a theoretical account are beginning to emerge. Our proposed separation of the discourse level of processing from various lexical and syntactic processes that underlie comprehension is only a temporary simplification, because there is surely interaction among these two broad categories of processing. All levels of processing consume resources to various degrees and affect the availability of resources required by discourse processes. It is quite likely that lexical-semantic process and syntactic processes will at times consume more resources than simple grapheme/phoneme processing as well as being constrained at times by contextual influence from the discourse-level processes. In fact, both the graded salience hypothesis (Giora, 1997) and the coarse-coding process (Beeman, 1998) can be viewed as lexical-semantic level processing which is constrained by context and likewise are utilized in developing a model of the text.

Basic LH sentence network (not uniquely a part of discourse processing)

As a text is being read, the individual words are being identified, the syntactic structure is being parsed and word meaning is being extracted. The basic reading processes are primarily left hemisphere functions. These basic processes include visual/graphemic processing, phonological processing, lexical-semantic processing and syntactic processing. Obviously, discourse level processing does not wait until all the lower levels are complete; discourse processing occurs on a word-by-word, moment-to-moment level in parallel with the lower levels of language processing. As each word is read, an interpretation of the word within the context of the passage is constructed. This interpretation is informed by a salience-based lexical access process, utilizing several left hemisphere regions.

Coarse RH semantic processing network

The relevant coarse semantic field for each word is activated in the right hemisphere. The possibility for an inference or alternative interpretation of a concept arises based on the degree that this newly active coarse semantic field overlaps with a recently activated coarsely-coded semantic field (either based on previous text or perhaps activated in response to world knowledge or schema related to the context or topic of the passage). Thus, whenever enough information accrues to support the generation of an inference, additional activation should be seen in the right temporal region. At this point several other accompanying cortical networks might activate in parallel.

Dorsolateral Prefrontal coherence monitor network

The dorsolateral prefrontal cortex will increase activity bilaterally in response to either a lack of coherence in the text (signaling the need for additional right hemisphere activity) or as a result of an unusually active semantic field in the right temporal region. This DLPFC activation can be viewed as goal directed behavior with respect to guiding the inference construction process. The guiding and reiterative nature of this process is dependent on available cognitive resources. As long as resources are available, the inferential process proceeds until a successful inference has been integrated and a reader-based standard of coherence has been achieved. If resources are consumed, the reader continues on through the text with whatever current interpretation exists; later information either supports the current interpretation or results in additional signals to an inference generation process, again checking available resources. This iterative process continues until coherence is achieved or a complete breakdown in comprehension occurs.

Left frontal-temporal text integration network

In addition to the lexical access and parsing which are traditionally viewed roles of the left hemisphere, the left inferior frontal gyrus and the left anterior superior temporal sulcus region extending into the temporal pole maintains, constructs and integrates information into the reader's understanding of the text. This "understanding" may be similar to the situation model or mental model of the text. It is still unclear where this representation is "stored" in the cortex. There have been several proposals concerning the storage of the situation model. Grafman (1995) has proposed frontal cortex storage of schema-level representations in meaning knowledge units (MKUs). Schmalhofer (2003) has proposed a right-hemisphere storage of the situation model, and Long and Baynes (2002) has suggested a bilateral representation of situation model.

Our hypothesis is that this representation is stored diffusely, distributed over areas of the cortex specifically suited to the nature of the information (e.g., spatial information in right parietal, emotional information in the amygdala/medial frontal cortex, etc.). Thus, these left hemisphere regions reach a higher level of activity when an inference is integrated into the discourse representation than during normal reading. This higher level of activity is only seen with respect to text that does not exceed the reader's capacity to process it; in contrast, when resources are unavailable to integrate the inference (due to either text that is difficult at another level or due to a reader's reading ability), integration of a possible inference fails or processing may be passed to the right hemisphere.

Medial frontal protagonist/agent interpreter network

The medial frontal gyrus is active during most narrative processing. This region seems to be particularly well-suited to processing information related to understanding another's plans and motivations. This can also be viewed as comprehension of an alternative reality, specifically the world-view of a protagonist within a text. Any inference that would be related to a characteristic specific to a protagonist within the story should result in activity in this region in response to the process of updating the *protagonist model*. Typically, Theory of Mind tasks also activate portions of the right posterior, superior temporal gyrus and the right inferior parietal lobe. It is likely that these areas are also part of this protagonist model network, but additional experiments are necessary to determine the full extent of the network. The medial frontal region has also been seen to increase its activity in response to text that is particularly emotionally oriented or one that requires the reader to reference emotionally based memories (Ferstl & von Cramon, 2002).

Intraparietal Sulcus Spatial network

Whenever a reader encounters sentences that load heavily on a spatial referent, activation appears in the left intraparietal sulcus area (Just et al., 2004). Just et al. presented readers with sentences like, "The number eight when rotated 90 degrees looks like a pair of spectacles." These high-imagery sentences resulted in additional activation bilaterally in the intraparietal sulcus relative to low-imagery sentences, although it was much stronger in the left hemisphere. Mason et al. (under review) also found additional left intraparietal sulcus activation for their novel metaphors, which were rated to be much more visualizeable than their literal sentences and frozen metaphor sentences. It is likely that the left intraparietal sulcus activates on most narrative texts due to the spatial information likely to be encoded in a situational model (Zwaan, 1998; Zwaan & Singer, 2003). This spatial network has not been given as much attention as the other networks in discourse processing research but should be expected to function in a similar manner as the other parallel networks proposed here. It should activate as a function of the text constraints as well as the reader's individual ability.

This theoretical framework is by no means a complete picture of discourse processing and the functions of several networks are still highly speculative. It is offered as a possible overview of how the various cortical networks may function in discourse. It is likely that several of the descriptions here will need to be revised in the light of additional data.

Relation to other theories

Throughout this chapter we have described research in this area that is consistent with various discourse processing theories. In addition, the research contained in this chapter has been fundamental in developing new concepts such as the coarse coding theory of right hemisphere process, the dynamic recruitment of cortical networks in response to text constraints, the spillover of processing to other differential specialized networks in response to capacity utilization, and the utilization of a Theory of Mind network in discourse comprehension. What remains is to examine how the recent cortically based perspectives on discourse processing fit into the various discourse processing theories.

The C-I model (Kintsch, 1988; Kintsch & van Dijk, 1978) has certainly been one of the most influential models of discourse processing. According to this model, the process of comprehending written text proceeds in two stages. The first is an initial construction stage in which the propositions of the text base are combined with the reader's knowledge base to construct a loose representation of the text. It is during this stage that whatever inferences are necessary to connect disjoint pieces of the text are generated. Then, during a subsequent integration stage, this representation is "pruned" to remove any propositions or connections that are inconsistent or contradictory. This second stage of processing is thought to result in a representation that is coherent. A relatively undefined aspect of the CI model is an initial liberal generation stage which occurs prior to the construction phase. This liberal generation stage presumably allows the generation of many inferences due to an interaction of the text and world knowledge. Readers attempt to construct and integrate only those inferences for which there is enough connection with the text. The C-I model centrally addresses the types of processes executed by the coarse

RH semantic processing network, the frontal (dorsolateral) coherence monitor, and the left frontal-temporal inference support network.

The 3CAPS model (Goldman & Varma, 1995) builds upon the C-I framework by incorporating the construction and integration stages within a more general cognitive architecture (Just & Carpenter, 1992). Discourse processing within this model is mediated by *productions*, or condition-action rules, that operate on the contents of a limited-capacity working memory system. Working memory is thus conceptualized as consisting of a limited pool of processing resources that can be allocated dynamically in the service of generating inferences. This position is entirely consistent with the proposal that the cortical networks in the brain are utilized via an interaction between the text variables and the availability of resources.

The resonance model (Myers & O'Brien, 1998) also shares some similarities with the C-I model and the 3CAPS-CI model. Like both CI models, text comprehension is a result of constructing a representation of the text on the basis connecting incoming text information with prior text information as well as information from the reader's world knowledge. Furthermore, the information that is contained in a short-term memory store at any one time is limited. The resonance model is consistent with the initial liberal inference generation mechanism of the CI model. O'Brien et al. (2004, p. 290) describe the resonance model as:

> passive reactivation processes [which] cannot be shut off. The signal that emanates from active components in memory is not triggered by coherence breaks, nor is it guided by relevance; it is continuous, autonomous, and unrestricted. Any related information that resonates in response to this signal has the potential to be activated, independent of its relevance. Outdated information is no different than any other information; if the reader encounters a target sentence that is related to the outdated information, the target sentence can serve to reactivate that information, even if reactivation ultimately disrupts comprehension.

Perhaps most interestingly, these passive memory based retrieval/generation processes are similar to the manner in which the coarse-coding hypothesis describes the activation of the coarsely coded semantic fields in the Coarse RH semantic processing network. Specifically, coarse-coded information in the right hemisphere is activated continuously, autonomously, and in an unrestricted manner. The information has the potential to be activated, independent of its relevance. However in coarse coding "independent" may not be the correct concept; the information has to be part of an overlapping coarsely coded semantic field. It remains to be seen how independent these fields are.

It would be convenient if there were a set of processes that always occurs whenever anyone is processing a text and if these processes could be mapped onto specific cortical regions. This approach, however, fails to acknowledge the dynamic nature of discourse comprehension and brain function. The brain, particularly in text comprehension, is an adaptive machine. For example, we can say that, in general, drawing an inference should result in right temporal activation, but it would be incorrect to make a simple claim such as the right temporal area is where an inference is generated. In fact, we have shown that at least three plausible theories have been developed to illuminate the right hemisphere's role in inference construction: the Reichle and Mason (in press) limited capacity inferencing component processes hypothesis; the Mason et al. (2004) right hemisphere inference integration hypothesis; and the coarse coding theory (Beeman, 1998).A similar account applies to the processes underlying figurative language comprehension (Bottini et al., 1994; Rapp et al., 2004). Trying to understand a metaphor has resulted in the engagement of right hemisphere. But here too, it would be too simplistic to claim that the right hemisphere is where a metaphor is processed. Specific types of metaphors also seem to activate a region in or near the medial frontal gyrus (Mason, Eviatar & Just, under review), a region which also activates during the processing of inconsistent emotional information (Ferstl, et al., 2005). And while the medial frontal area is active during the processing of some types of metaphors, it may be due to the type of the metaphor rather than a metaphor per se.

This leaves us with the rather difficult task of proposing that if a text has high emotional content, invites an elaborative inference, and has a clear topic, we should see a specific type of network active. Developing a set of networks that process discourse would be as many and as varied as the texts themselves. The better approach would be to build upon already existing theories of discourse and show how evidence from brain regions support components of the various theories.

Giora's graded salience hypothesis (Giora, 1997) provides another example of how these new perspectives on discourse theories are consistent with previously proposed models. The graded salience hypothesis proposes that two different mechanisms, one modular linguistic mechanism (a bottom-up, perceptual lexical access of the salience ordered mental lexicon) and one global, contextually based access system that operates in parallel to the lexical access. Peleg, et al. (2001) notes that it is not a specific word's predictiveness that is important for contextual facilitation but rather a concept's availability and predictability with respect to previous world-based encounters. Consider how this might function with respect to metaphor interpretation. It is possible that the access of a concept proceeds both locally in the left hemisphere and globally in the right hemisphere. Again, the similarity between this account and the processing of the coarse RH semantic processing network is clear.

Concluding remarks

Discourse processing is a complex high-level cognitive task in that many facets of cognition are involved. The ability of neuroimaging research to examine a large scale cortical network of differentially specialized brain regions while manipulating the loading of the various facets of cognition makes the methodology ideally suited to advancing our understanding of discourse comprehension. The diverse nature of the research reviewed in this chapter shows that we are only beginning to bring to bear the strengths of neuroimaging on our understanding of comprehension.

At the outset, we proposed that neuroimaging allows a new way to study old theories as well as providing data which might suggest new theories underlying discourse comprehension. The ability to use neuroimaging to examine whole cortical networks enables speculation as to how the various component processes of diverse discourse theories can be integrated into a single whole. Much of the neuroimaging research completed so far can thus serve as existence proofs for several proposed discourse processes. While neuroimaging research may not yet be at the stage of "falsifying" a theory, it can be used to support several theories.

In conclusion, it is quite evident that neuroimaging offers an ability to investigate discourse processing in a manner that has not been done before. The greatest advantage of this research approach is the ability to examine the network as a whole, revealing new aspects of discourse processing.

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