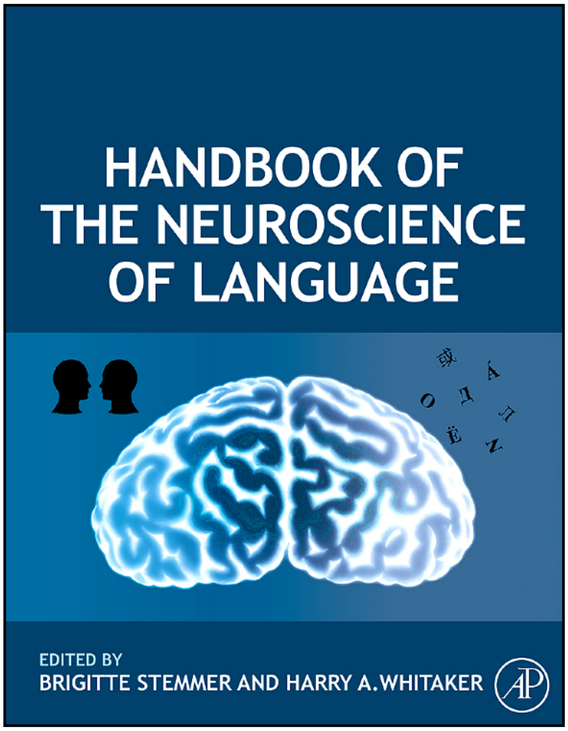

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C H A P T E R

16

The Neural Bases of Text and Discourse Processing

CHARLES A. PERFETTI and GWEN A. FRISHKOFF

Learning Research and Development Center, University of Pittsburgh, Pittsburgh, PA, USA

ABSTRACT

Understanding discourse requires the comprehension of individual words and sentences, as well as integration across sentence representations to form a coherent understanding of the discourse as a whole. The processes that achieve this coherence involve a dynamic interplay between mental representations built on the current sentence, the prior discourse context, and the comprehender's background (world) knowledge. In this chapter, we outline the cognitive and linguistic processes that support discourse comprehension and explore the functional neuroanatomy of text and discourse processing. Our review suggests an emerging picture of the neurocognition of discourse comprehension that involves an extended language processing network, including left dorsal and ventral frontal regions, left temporal cortex, medial frontal cortex, and posterior cingulate. While convergent evidence points to the importance of left frontal and temporal networks in discourse processing, the role of right hemisphere networks is less clear.

16.1. INTRODUCTION

In text and discourse processing, a central idea is that of *coherence* – meaningful links that make a discourse "hang together" between adjacent sentences (*local coherence*) and across larger units (*global coherence*). The goal of this chapter is to describe how the brain supports cognitive and linguistic processes that help establish discourse coherence. We begin by asserting the obvious: text and discourse comprehension engage neural systems that are implicated in language perception (auditory or visual language input), word processes, and sentence comprehension. In addition, when directly compared with word- and sentence-level comprehension, discourse comprehension appears to recruit other areas, including left prefrontal cortex (PFC), anterior temporal regions, medial frontal cortex, and the posterior cingulate. These regions have been related to general cognitive mechanisms (e.g., attention, memory) that are necessary for the retrieval and maintenance of mental representations across time, as well as to language-specific devices for linking meanings within and across sentences.

While the evidence reviewed here leads to convergent findings, it also suggests some current controversies and areas where further work is needed. One such area concerns hemispheric asymmetries in text and discourse comprehension. While studies of patients with right hemisphere damage have been taken to suggest a unique role for the right hemisphere in discourse comprehension, recent work suggests a need for more refined theories and additional studies, to reconcile the current body of evidence on the left versus right hemisphere contributions to discourse processing.

16.2. COGNITIVE AND LINGUISTIC PRINCIPLES OF DISCOURSE PROCESSING

In this section we review major ideas from the psycholinguistics of text and discourse comprehension. This prior work suggests that comprehenders strive to build coherent representations, or what are called *mental models*, during text and discourse processing. Mental models are built from *propositions* – the "idea units" of language. The challenge for a neural theory of discourse comprehension is to identify the neurocognitive and neurolinguistic mechanisms that serve to link together successive propositions. In what follows we discuss two types of mechanisms, inferential processes and discourse-grammatical cues. Together, these processes help to establish text and discourse coherence. In following sections, we discuss the neural underpinnings of these processes.

16.2.1. Mental Models in Text and Discourse Comprehension

Text researchers use the term proposition to refer to the basic semantic units – the "idea units" – of a text or discourse. In effect, propositions represent the core ideas expressed in a sentence or clause – an action, event, or state of affairs involving one or more participants (e.g., "Jack slept," "John kissed Mary," "The ball is round"). In "Harry let Fido out," the meaning of the verb (*let … out*) entails that Harry carried out some action that resulted in Fido changing locations from inside (some place) to outside. The fact that we tend to interpret this sentence as *Harry let the dog out of the house* illustrates the role of background knowledge: "Fido" is the name of a dog, and "letting out" describes a common event in a household with pets. Thus, a proposition encodes basic relational meanings, partly independent of syntactic expression, while the proposition plus relevant knowledge yields a specific meaning or interpretation.

Establishing coherence across sequences of propositions involves additional processes that extend beyond the single sentence. Words become linked to referents introduced in prior text, or established through cultural transmission of knowledge (e.g., that "Fido" is the name of a dog). As these links are made, the comprehender builds a representation of what the text is about, a *mental model*.

In fact, according to the influential model developed by Kintsch and van Dijk (see Kintsch and Rawson, 2005), comprehension involves not one mental model, but two. (1) A model of what the text says (the *text base*, consisting of ordered propositions) and (2) a model of what the text is about (the *situation model*). The propositional structures of the text base are extracted from sentences, accumulate across successive sentences, and are supplemented by inferences necessary to make the text locally coherent. The situation model is formed from the text base by combining knowledge sources through additional inference processes. A text base thus amounts to a representation of meaning that is close to the language of the text, essentially amodal and propositional. In contrast, a situation model comprises nonpropositional and nonverbal information, and may include modality specific (e.g., visual–spatial), as well as semantic representations (Mellet *et al.*, 2002). Explaining the nature of these representations, how they are formed, and how they are maintained and integrated during online comprehension is central to theories of text and discourse comprehension.

16.2.2. Grammatical Markers of Discourse Coherence

The text processing view treats discourse as linguistic input to be understood by an individual reader. A complementary view, grounded in linguistic insights, emphasizes the socio-pragmatic nature of discourse, and proposes that a key function of grammatical systems is to support alignment of speaker/hearer representations during communication (Givón, 2005). According to this framework, the linguistic structures that support communication operate as socio-pragmatic cues. For example, a pronoun ("he," "she," "it," and so forth) cues the comprehender to link a previously mentioned referent (John, Mary, the ball). To use these cues appropriately, a speaker (or writer) must consider not only the propositional information to be encoded, but also the knowledge and intentional states of the comprehender. For example, referring to John's daughter has a different cueing effect depending on whether the comprehender knows John and, in particular, whether he knows that John has a daughter. If not, then referring to John's daughter out of the blue can lead to a breakdown in communication – from the comprehender's viewpoint, a break in coherence.

The text perspective and the discourse-grammatical perspective converge to identify coherence as a key issue in language comprehension. Functionalist accounts of discourse-grammatical structures describe the linguistic mechanisms that serve communication through coherence. Many of these mechanisms operate at the level of *local* coherence, preserving stretches of conversation (and text reading) from coherence breakdowns. These mechanisms must operate in close concert with cognitive (attentional, working memory) and socio-emotional processes that are relevant for communication (see Box 16.1). Theories of text comprehension, in turn, provide complementary insights on how inferences can function to help establish *global*, as well as local, coherence.

16.2.3. Inferencing and Coherence

Prior work (e.g., Gernsbacher & Robertson, 2002) has identified various types of coherence links, including those that establish continuity of the discourse topic or theme (*referential coherence*), event time and location (*temporal and spatial coherence*), and causal or intentional relationships between events. Here we focus on referential coherence to illustrate some general principles.

Building on our previous example, consider the following text sample (from Sanford & Garrod, 2005):

1. In the morning $\textit{Harry}_1$ let out $\textit{his dog Fido}_2$.
2. In the evening $\textit{he}_1$ returned to find $\textit{a starving beast}_2$.

Note the use of a pronoun "he" in sentence (2): this expression is typically understood to refer to the same real-world entity as the name "Harry" in sentence (1), a phenomenon called *coreference*. A variety of anaphoric devices (definite articles, pronouns) and deictic expressions ("this" or "that") signal coreference in English. These devices are part of a grammatical system that provides instructions

Box 16.1 Individual differences in working memory and discourse: evidence from ERPs

Reading researchers have long suspected that discourse comprehension is tied to working memory (WM). The challenge in comprehending text is precisely that of activating relevant information at the appropriate time, storing information in short-term memory, and reactivating information as needed to support referential links across clause and sentence boundaries. In support of this view, Ericsson and Kintsch (1995) cite studies that suggest "reading span" (a measure developed by Daneman & Carpenter) predicts text comprehension skill, even after controlling for other reading and language skills.

In ERP studies, researchers have identified a pattern known as the "left anterior negativity" (LAN) that is active during sentence and discourse comprehension and that varies with WM skill (King & Kutas, 1995). The LAN occurs relatively early (t150–300 ms) and is strongest over left anterior electrodes, consistent with early activation of the left PFC. Interestingly, the LAN responds not only to variations in syntax that may affect WM, but also to cues that can affect memory strategies, even when syntactic structure is held constant. For example, Münte *et al*. (1998) examined variations in LAN in two conditions where the sentence structures had identical syntax, but differed in the temporal (referential) links between successive clauses.

1. *After* we submitted the article, the journal changed its policy.
2. *Before* we submitted the article, the journal changed its policy.

In (1), the initial word (*after*) cues the comprehender that the order of the two events is the same as the order of the two clauses that encode these events. In (2), the intial word (*before*) indicates that the temporal order will be different from the surface order. Interestingly, subjects with high WM scores showed a greater LAN in (2). This evidence may point to more effective memory strategies among high comprehenders.

Ericsson, K.A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, *102*(2), 211–245.
King, J., & Kutas, M. (1995). Who did what and when? Using word- and clause-level ERPs to monitor working memory usage in reading. *Journal of Cognitive Neuroscience*, *7*, 376–395.
Münte, T.F., Schiltz, K., & Kutas, M. (1998). When temporal terms belie conceptual order. *Nature*, *395*(6697), 71–73.

for how to make a discourse locally coherent. In the words of Givón (2005), the key function of grammar is to provide an "*automated* discourse processing strategy" (italics added).

A second instance of coreference in this same example illustrates *backward, or bridging, inference*. The first noun phrase (NP), "a starving beast," in sentence (2) is understood to refer to the same real-world entity as "his dog Fido" in sentence (1). Note that the second NP is marked by an indefinite article (a). This contrasts with the usual practice of using the definite article to signal "old" or "given" (i.e., previously mentioned) information. The nonstandard use of "a" in this context cues the comprehender to draw an inference: Fido was not starving in the morning when Harry left. This further allows the inference that Fido had no food during the time that Harry was gone. In this case, the coherence device is the use of two different NPs that must be made coreferential for the text to be coherent.

Finally, whereas backward inferences are often obligatory, *forward or predictive inferences* are strictly optional and can be costly to processing resources. They may not be made except when compelled by a need for either textual or causal coherence (for reviews, see Beeman *et al*., 2000; Perfetti *et al*., 2005).

16.2.4. Summary

Readers strive to develop some degree of coherence in the meaning they derive from a text. To do this, they establish links within and across sentences, using grammatical cues and drawing various kinds of inferences. Grammatical devices cue relatively automatic processes that help to establish coherence links, but such links also can be established through inferences, which engage additional processes that depend on the comprehender's standard for coherence, cognitive capacity, and language skills.

Understanding how these multiple processes are coordinated in real time during text and discourse comprehension requires an explicit theory of cognitive and neural mechanisms – the focus of remaining sections in this chapter.

16.3. THE NEUROSCIENCE OF TEXT AND DISCOURSE COMPREHENSION

Recent reviews (Mar, 2004; Ferstl, 2007) attest to the growing interest in the neural basis of text and discourse comprehension. Our discussion, which benefits from these prior reviews, will conclude that language comprehension involves a left-lateralized network of brain areas with limited and task-specific involvement of the more anterior, dorsal and ventral, and prefrontal areas. The controversial role of right versus left hemisphere contributions will be addressed in Section 16.4.

16.3.1. The Role of the Temporal Lobes in Discourse Comprehension

To discover what is special about text and discourse processing, it is important to consider direct comparisons of brain activation elicited by discourse with activation to isolated words, sequences of (unconnected) words, and (unconnected) sentences. A number of imaging studies have included such comparisons. When connected discourse or isolated (unconnected) sentences are compared with word lists, the anterior temporal lobes show greater activation (Mazoyer *et al*., 1993). Given prior research linking anterior temporal lobes to semantic comprehension (see Chapter 5), increased activity in anterior temporal lobes may reflect added demands for semantic processing in comprehending connected text.

Additional evidence for the role of anterior temporal lobes in discourse-level semantic processing has come from electromagnetic (event-related potential, ERP and magnetoencephalography, MEG) studies. The N400 component (and its MEG counterpart, the mN400), has consistently been linked to neural sources in the anterior temporal lobe (see Van Petten & Luka, 2006 for a recent review). Interestingly, the N400 response has been found to vary with demands on sentence- and text-level integration, as well as word-level semantic comprehension. For example, in a recent study, Hagoort *et al*. (2004) presented sentences, such as *The Dutch trains are yellow/white/sour and very crowded*. Dutch subjects know very well the famous yellow trains of the Netherlands, so when the word *white* appears they know the sentence is false. The N400 elicited by the pragmatic anomaly (*white*) was indistinguishable in latency and distribution from the N400 to the semantically anomalous ending, *sour*. When they presented the same materials in an functional magnetic resonance imaging (fMRI) task, Hagoort *et al*. (2004) found that *sour* and *white* both produced increased activation in the left inferior PFC and near areas associated with semantic processing, including the left temporal lobe (for an illustration see also Box 17.1). Although more work is needed on whether the brain honors the distinction between semantics and pragmatics, this study at least suggests that it is the comprehender’s knowledge, whether based on what is true or what is sensible, that is reflected in N400 measures of semantic integration. Likewise, this may suggest that the increased temporal lobe activity in processing connected discourse, versus unconnected sentences, reflects a difference in degree, rather than one of kind.

By combining results from recent fMRI and ERP studies, we can conclude that the anterior temporal lobes are important in sentence- and text-level semantic integration. This leads back to our original question: What, if anything, is unique to text-level processing?

16.3.2. The Role of PFC in Discourse Comprehension

The difference between text and sentence processing comes to this: in reading text, information must be integrated across sentence boundaries to maintain coherence. Studies that compare connected discourse with sentences that lack global coherence (Mazoyer *et al*., 1993) suggest that one locus for routine integration processes that are supported by coreference (e.g., based on argument overlap) is the superior dorsomedial prefrontal region (BA 8–9). This region also appears to be involved when integration demands long reaches for knowledge. For example, Ferstl and von Cramon (2001) had subjects read sentence pairs that lacked explicit overlap to support integration:

1. *The lights* have been on since last night. *The car* doesn't start.

2. Sometimes *a truck* drives by the house. *The car* doesn't start.

When sentences could be linked through a backward inference, as in (1), activation was greater in the superior dorsomedial prefrontal region and posterior cingulate cortex. When cohesive ties were added to the second sentence to suggest a link to the first, for example, *that’s why the car doesn’t start*, increased activation was observed in left PFC for the unrelated case (2) but not the related cases (1). Ferstl and von Cramon (2001) suggest the activation in the unrelated case with the “why” phrase added reflects additional processing required to reconcile the linguistic information in favor of integration (this is why) with the pragmatic understanding that the car’s starting and the truck’s passing are unrelated.

An fMRI study reported in Schmalhofer and Perfetti (2007) provides additional support for a frontal-medial response during inferencing. Adapting the materials and procedure of the ERP study by Yang *et al*. (2007) (see Box 16.2), this study had subjects read two-sentence passages that varied the ease of integration between a target word and the information from a preceding sentence. When integration was possible only by making a predictive inference in the first sentence, higher activation was observed in superior dorsomedial PFC (BA 8–9). Additional activation in left (but not right) ventral PFC was linked to verification judgments that were performed later in the task. In this part of the task, subjects were asked to decide whether an event (e.g., wine spilled) was or was not implied by the previous two sentences. For example, when the first sentence referred to turbulence during a flight while wine was being served, *wine spilled* typically elicited a “yes” response. During the verification judgment, the inference condition produced additional activation in left (but not right) inferior frontal gyrus, suggesting additional processing during the judgment, and implying that the predictive inference (that wine spilled) was not explicitly made during the reading of the first sentence. These results replicate findings from the behavioral literature,

Box 16.2 Individual differences in inferencing: evidence from ERPs

Studies of text comprehension have consistently found individual differences in readers' ability to make coherence links. A recent ERP study by Yang *et al*. (2007) examined different types of word-to-text integration among strong and weak readers. The main interest was in the N400 response to the second mention of a referent (e.g., *explosion*) in relation to the first mention in a previous sentence. There were three conditions which differed in the extent to which the first sentence established a referent that could be accessed at the word *explosion* in sentence 2 (see Table).

The amplitude of the N400 to the critical word (*explosion*) was reduced when the previous sentence had referred to an explosion (referentially explicit condition). It was also reduced when the previous sentence had referred to explosion using different words (referentially paraphrased condition). Importantly, there was no reliable N400 reduction when the critical word was related to the prior sentence only by inference (inference condition). There was, however, substantial variability among subjects in this condition, consistent with individual differences in the tendency to make forward inferences (see Box 16.3). Thus, explicit and meaning-based paraphrase relations patterned together in reducing the N400, whereas a process that depended on the situation model to generate an inference did not. Adults classified as low skill in comprehension showed weaker and slower (sluggish) integration effects, especially for the paraphrase condition. Thus, while these results do not suggest that making inferences is necessarily a problem for low comprehenders (but see Box 16.3), they suggest that making word-based meaning connections is likely to contribute to difficulty in text comprehension.

Experiment Conditions in Yang *et al.* (2007)

Condition	Sample passage
Explicit	After being dropped from the plane, the bomb hit the ground and *exploded*. The *explosion* was quickly reported to the commander.
Paraphrased	After being dropped from the plane, the bomb hit the ground and *blew up*. The *explosion* was quickly reported to the commander.
Inference	After being dropped from the plane, the bomb hit the ground. The *explosion* was quickly reported to the commander.
Unrelated	Once the bomb was stored safely on the ground, the plane dropped off its passengers and left. The *explosion* was quickly reported to the commander.

Yang, C.-L., Perfetti, C.A., & Schmalhofer, F. (2007). Event-related potential indicators of text integration across sentence boundaries. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(1), 55–89.

Box 16.3 The role of working memory in forward inferencing

Working memory plays an integral role in text and discourse comprehension, and several influential theories have been advanced to explain how inferential processes may be linked to working memory capacity (see Sanford & Garrod, 2005, for a recent review). In an EEG study, St. George *et al*. (1997) found that individual differences in working memory skill affect EEG measures under conditions that promote forward inferencing (see Box 16.2). Probe sentences were presented (e.g., *the turkey burned*) representing forward inferences that could be drawn from a previous text (e.g., *she forgot about the turkey in the oven*). Whereas readers with high working memory capacity showed N400 effects in this forward inference condition, readers with low working memory capacity did not. These results are consistent with the idea that forward inferences are optional and are made only under certain circumstances that vary with texts and reader dispositions. These findings support prior work that has emphasized individual differences in text and comprehension (see Perfetti *et al*., 2005).

Perfetti, C., Landi, N., & Oakhill, J. (2005). The acquisition of reading comprehension skill. In M.J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 227–247). Oxford: Blackwell.
Sanford, A.J., & Garrod, S.C. (2005). Memory-based approaches and beyond. *Discourse Processes*, *39*(2–3), 205–224.
St. George, M., Mannes, S., & Hoffman, J.E. (1997). Individual differences in inference generation: An ERP analysis. *Journal of Cognitive Neuroscience*, *9*(6), 776–787.

and suggest that left ventral and dorsomedial PFC may be important in certain inferencing processes.

In reviewing the fMRI research on inferencing, Ferstl (2007) concludes that there is clear evidence for a contribution of dorsal medial PFC to the process of establishing coherence from sentences; across studies, however, the results are variable, and further work is needed to map this activity to specific cognitive and linguistic processes that support discourse coherence.

ERP research has provided additional evidence for engagement of prefrontal processes in discourse comprehension. In addition to the N400, which is associated with semantic processes, an earlier negativity, more frontal in its distribution, may be associated with referential processes in both written and spoken language comprehension (Van Berkum *et al.*, 2003). Van Berkum *et al.* (2003) found that when the referent of a NP was ambiguous (e.g., "the girl" when the discourse had previously introduced two different girls), there was an early negativity (peak at 300–400 ms) with a frontal distribution that was distinct from the N400, where central and parietal recording areas tend to be most affected by meaning congruence. An open question is how this response may be related to the left anterior negativity (or LAN), which has been linked to early syntactic processing (see Box 16.1; Chapter 9) and to the medial frontal negativity, identified in prior work on word- and sentence-level semantic comprehension (see Chapter 5).

In summary, what seems remarkable (but probably should not be) is that text processing shows the pattern of activation observed in sentence processing. Both tasks involve temporal lobe and prefrontal (inferior frontal gyrus) activation. In addition, both tasks recruit dorsal PFC in response to task demands (Ferstl, 2007). An apt conclusion from Ferstl is that "… in the absence of an overt, demanding comprehension task, language processing in context proceeds with surprisingly little brain power" (Ferstl, 2007, p. 66).

16.4. RIGHT HEMISPHERE CONTRIBUTIONS TO DISCOURSE COMPREHENSION

Research based on lesion studies has implicated right-cortical regions in certain discourse-pragmatic comprehension tasks (for a review see Chapters 17 and 28). By contrast, our review suggests that both sentence and text processing are generally bilateral and left dominant. On the other hand, a few studies have reported larger right lateralized in discourse comprehension (Robertson *et al.*, 2000). In this section, we review evidence for and against enhanced right hemisphere activity in discourse processing.

16.4.1. Evidence on Right Hemisphere Contributions to Inferencing

Although both the right hemisphere discourse functions and their neural anatomy remain somewhat unclear, some studies find evidence for right hemisphere involvement in inference making. Beeman *et al.* (2000), for example, used a divided visual field paradigm and had subjects name words related to possible inferences. The authors observed priming of words related to forward (predictive) inferences that was restricted to the left visual field and thus the right hemisphere. By contrast, activation of backward (bridging) information immediately after the "coherence break" – when new information was presented that required a bridging inference – was greater in the right visual field (left hemisphere).

Robertson *et al.* (2000) provide additional support for right hemisphere contributions to discourse coherence. In an fMRI study, they presented lists of sentences that contained exclusively either indefinite or definite NPs (a/the child played in the backyard; a/the mother talked on the telephone). The indefinite NP condition produced more activation in anterior cingulate cortex and the left inferior frontal gyrus. The definite NP case produced more activation in right inferior frontal gyrus. This result was interpreted as consistent with the hypothesis that the right hemisphere contributes specifically to integration processes. However, note that lists of sentences with definite articles and no argument (NP) overlap are still lists, and thus require backward integration on every sentence to establish local coherence. Thus, if backward inferences were made in the definite NP condition, then activation of the right hemisphere in this study would be inconsistent with the findings of Beeman *et al.* (2000), who observed priming of backward inferences only in the right visual field (left hemisphere).

Processes that work on either coherent or incoherent texts are serving the construction of a coherent situation model, and right hemisphere temporal and prefrontal areas may be involved in some circumstances (e.g., Ferstl, 2007). On the other hand, there is evidence that posterior cingulate cortex, left anterior temporal, and prefrontal areas are involved in different aspects of the construction job. Maguire *et al.* (1999) used pictures to guide coherence for otherwise incoherent stories and compared the results with easily comprehensible stories. They concluded that the posterior cingulate cortex was especially involved in the successful construction of a situation model. Cingulate activation was higher during the second presentation of a story (which should facilitate the situation model) and when a picture had been present for an incoherent story. Further, cingulate activation was correlated with comprehensibility ratings. In addition, Maguire *et al.* (1999) identified the left anterior temporal lobe with processing of incoherent versus coherent stories; activation was also correlated with recall. They also identified two prefrontal areas: the anterior lateral PFC was associated with recall and with the second presentation of a story, while a ventral medial PFC area (BA 11) was more active in coherent than incoherent (and no-picture) stories and was associated with comprehensibility ratings. This study provides a fuller picture of the integrative and memory processes that must occur in text comprehension as a function of the obstacles imposed on building coherence. However, it reveals no special right hemisphere involvement.

16.4.2. A Special Role for Right Hemisphere Processing in Global Coherence?

As discussed in Section 16.2, text research has been concerned not only with the processes that establish local coherence, but also with the processes that sustain global inferences and support the situation model. According to one view, it may be precisely at the level of global integration that we should expect to see evidence for enhanced right hemisphere processing in discourse comprehension (Beeman *et al.*, 2000; Robertson *et al.*, 2000).

Causal inferences provide one means of effecting global coherence in text comprehension. Mason and Just (2004) correlated behavioral results with imaging data, varying the causal distance between two sentences. For example, the target sentence *The next day his body was covered with bruises* followed one of these three sentences:

1. Joey's brother punched him.
2. Joey's mother got angry at him.
3. Joey went to a friend's house.

Sentence (1) provides a close causal connection for the target sentence, whereas (3) can be causally linked to the target only through a chain of inferences. Sentence (2) is intermediate, requiring a plausible causal inference. Consistent with Ferstl and von Cramon (2001), Mason and Just found that lateral prefrontal activation increased slightly with reduced coherence, but they also found that right frontal–temporal regions were most active when the target was preceded by the intermediately related sentence (2). This increased activation may reflect the memory demands of the successful bridging inference made in the intermediate condition, as suggested by Mason and Just (2004); but see Ferstl (2007) for a different interpretation based on the coarse coding hypothesis.

Although global coherence depends on inferences of various kinds, it depends more fundamentally on referential and coreferential binding, a process that inferences support. Syntactically well-formed sentences can be linked together so as to resist referential binding, producing the effect of a vague and hard to comprehend text. A title for such a text can help support global coherence. St. George *et al.* (1999) found that vague texts presented with titles produced left-lateralized temporal activation, whereas untitled texts produced bilateral temporal activation. This right hemisphere involvement in reading incoherent texts differed from the results of Robertson *et al.* (2000). Not only are the right hemisphere areas different in the two studies (inferior and middle temporal versus lateral PFC) – the direction of the coherence effect was different. The prefrontal area identified by Robertson *et al.* (2000) was associated with easy coherence (sentences linked through definite articles), whereas the right temporal areas of St. George *et al.* were associated with incoherence. Thus, right temporal activation may reflect support for more difficult processing, rather than reflecting a routine role in building coherence. If the reader is working to integrate information across sentences, additional memory resources may be required when this task is possible but difficult (Mason & Just, 2004). It is therefore important to control the difficulty across task conditions in order to link right hemisphere activations specifically with processes related to coherence making.

16.4.3. Right Hemisphere Involvement in Processing Nonliteral and Emotive Discourse

Stories often reflect multiple levels of meaning, for example a literal and metaphorical level or a literal and a moral of the story level. A general conclusion from imaging results is that acquiring these nonliteral meanings involves right hemisphere functions. An often-cited study using Aesop's fables (Nichelli *et al.*, 1995) concluded that the right hemisphere is "where the brain appreciates the moral of a story." The authors observed that the right inferior frontal gyrus and the right anterior temporal lobe were more activated when subjects judged whether an animal character represented a story moral, than whether the character had some specific physical feature.

However, there is reason to question the broader generalization that comprehension of nonliteral meaning generally relies on right hemisphere processing. Rapp *et al.* (2004) presented literal and metaphorical sentences for judgments of emotional valence. For example, the lover's words are harp sounds is a metaphor that would produce a positive valence rating. In comparisons between literal and metaphoric sentences, Rapp *et al.* (2004) found only three areas of greater activation for metaphors, and all were left lateralized: inferior frontal gyrus, and both anterior and inferior temporal lobe areas. Task differences may explain the discrepancy between this study and those that find right hemisphere involvement in nonliteral meaning. However, an interesting theoretical possibility suggested by the Rapp *et al.* (2004) results is that similar left hemisphere semantic processes are engaged across literal and nonliteral meanings and that metaphors require more of those semantic processes in the absence of supporting context.

Furthermore, recent studies have reported activation of the dorsal medial PFC during moral judgments (Greene *et al.*, 2001; Moll *et al.*, 2002) and ethical judgments (Heekeren *et al.*, 2003). Similarly, in research on understanding humor, early conclusions that the right hemisphere has a special role for jokes (Brownell & Martino, 1998) are qualified by later studies. Goel and Dolan (2001), for example, report increased activation in the left inferior frontal gyrus and in bilateral posterior temporal cortex (both inferior and middle) during the reading of jokes relative to humorless continuations of the same sentence.

Given such results, a tentative generalization is that the processing of nonliteral themes is supported by an extended left-lateralized language network that includes frontal areas. This network is also engaged in other more literal language tasks, including those that involve inference and evaluation, and may be supplemented by right hemisphere temporal and frontal areas under some circumstances. However, the

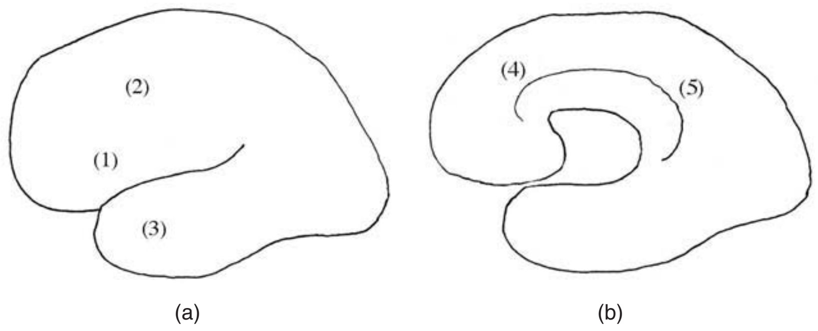

FIGURE 16.1 (a) Left lateral and (b) medial views of the brain, showing major areas that are differentially active during discourse versus word and sentence comprehension. (1) ventral PFC (inferior frontal gyrus); (2) dorsolateral PFC; (3) anterior temporal cortex; (4) anterior dorsomedial cortex (including anterior cingulate); and (5) posterior medial cortex, including posterior cingulate and precuneus.

precise role of the right hemisphere in inferencing and evaluation remains to be determined.

16.5. SUMMARY AND CONCLUSIONS

We began by observing that progress in mapping brain functions to processes in discourse comprehension requires attention to what has been learned in cognitive and psycholinguistic research. To date, this body of research suggests that text understanding, rich in implied as well as literal meaning, does not replace the comprehension of words and sentences, but builds on it. According to this view, there is a distinction between a text and the situation it describes; at the same time construction of a situation model still relies on basic comprehension of words and sentences.

Similarly, evidence from the cognitive neuroscience of text and discourse processing generally supports the assumption that areas of the brain that are active during sentence comprehension also support the comprehension of connected text. When listeners encode sentences, left hemisphere language mechanisms are involved in perceiving words, encoding their meanings, parsing the sentence, and integrating the meanings across sentences. The resulting integration of information is realized at two levels: (1) coherent semantic representations of successive clauses and sentences that are subject to verbatim memory loss at clause and sentence boundaries and (2) a situation model based on the updating of information as the text proceeds. What do we know about how the brain represents these two levels of comprehension?

Ferstl (2007) suggests a broad extended language network that supports text comprehension. It involves the lateral PFC, including the inferior frontal gyrus and the dorsolateral PFC, the anterior temporal lobes, including the temporal pole, the dorsomedial PFC, including the anterior cingulate cortex, and the posterior cingulate cortex (Figure 16.1).

Within ventral PFC, the inferior frontal gyrus routinely supports phonological and syntactic functions that are present in language processing generally. The triangular structure within the inferior frontal gyrus supports semantic integration with context. Other areas in ventral PFC, especially the posterior lateral PFC, are recruited when the task demands, or the comprehender's goals require, attentional resources. The anterior temporal lobe functions range over basic sentence comprehension, including processes that correspond to assembling propositions from sentences and mechanisms that link propositional information across sentence boundaries. Underlying these text functions are basic memory functions. For the dorsomedial PFC, the function is so far less precise in its correspondence to a cognitively specified comprehension process. The variety of tasks that elicit dorsomedial PFC activity makes it unlikely that the function of the dorsomedial PFC will be identified in discourse-specific terms, outside of general cognitive processing. Furthermore, within each of these broad areas, the specific neural structures and their exact functions are subject to different interpretations and can be identified more specifically only with considerable hedging.

If we apply this tentative characterization of a language comprehension network extended to handle texts, we do not see a simple mapping of anatomy onto the two levels of text comprehension theory. The text base, the understanding of the words and sentences, relies heavily on areas in ventral PFC, but also requires dorsolateral PFC and anterior temporal cortex. The construction of the situation model is distributed across this network, as far as we can tell. Of course, there should be no surprise to learn that the components of text processing are distributed rather than localized. They depend fundamentally on processes of information encoding, memory, and retrieval, along with basic left hemisphere language processes. The first set – those that support the general cognitive resources that must be part of comprehension – are distributed. The traditional localization of language functions, particularly syntax within the inferior frontal gyrus, provides a structure that is inherited by text-level processing. Thus, the ironic conclusion is that the only special structures for text processing are those that are special for language processing. Beyond these, text processing requires broadly distributed brain resources for the various cognitive, social, and affective processes that are integral to language and communication, including domain-general processes for memory updating that involve the (anterior and posterior) cingulate cortex.

16.6. CHALLENGES AND FUTURE DIRECTIONS

One key challenge for future work will be to reconcile contradictory evidence on the role of the right hemisphere in establishing coherence in discourse comprehension. The work reviewed here suggests several ways in which the right hemisphere may contribute to discourse processing: in supporting backward (versus forward) inferences, in helping to establish global (versus local) coherence, in recruiting additional memory resources, and in processing nonliteral and social/affective meaning. However, results are by no means consistent across studies, and detailed methodological and task analyses will be required to understand these differences.

Another topic that is ripe for future research concerns the nature of syntactic processes, and their interactions with communicative processes. According to functionalist views of syntax, morphosyntactic markers (e.g., pronouns, articles) can be considered overt, automated, and obligatory cues to perform certain discourse-pragmatic functions (e.g., linking referents across clause and sentence boundaries). The question remains whether regions that have previously been linked to syntactic processing (e.g., the anterior region of left inferior frontal gyrus) are also implicated in the kind of communicative inferences that may be required for two individuals to effectively track not only the current theme of a conversation, but also the attentional focus and knowledge states of one another.

Finally, neuroimaging studies of discourse comprehension may add to our understanding of individual differences (Boxes 16.1–16.3). As these studies reveal mechanisms that help explain differences in linguistic and communicative competence, they may lead to practical, as well as theoretical results, with implications for clinical and educational research, as well as for the neuroscience of language.

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Further Readings

Reading related to Section 16.2: Cognitive and Linguistic Principles of Discourse Processing

Givón, T. (2005). Grammar as an adaptive evolutionary product. In T. Givón (Ed.), *Context as other minds: The pragmatics of sociality, cognition and communication* (Chapter 4, pp. 91–123). Amsterdam: J. Benjamins.

This chapter considers how grammatical structures may be related to a variety of cognitive and communicative functions. Givón proposes that major subsystems in language are linked to different memory systems. These cognitively based processes provide basic tools for establishing discourse coherence. Givón also provides numerous examples of what he terms "discourse-pragmatic" markers in language, including morphosyntactic devices for establishing discourse coherence. The perspective represented here is one that shows how linguistic markers can be linked to specific socio-pragmatic goals that motivate human discourse, and communication.

Perfetti, C., Landi, N., & Oakhill, J. (2005). The acquisition of reading comprehension skill. In M.J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 227–247). Oxford: Blackwell.

This chapter provides a thorough introduction to Kintsch's Construction Integration Theory, and discusses the cognitive and linguistic mechanisms that are implicated in reading comprehension. Individual differences in cognitive and linguistic skills are also linked to individual differences in discourse comprehension, and to a theory of reading development.

Readings related to Section 16.3: The Neuroscience of Text and Discourse Comprehension

Ferstl, E.C. (2007). The functional neuroanatomy of text comprehension: What's the story so far? In F. Schmalhofer & C.A. Perfetti (Eds.), *Higher level language processes in the brain: Inference and comprehension processes* (pp. 53–102). Mahwah, NJ: Erlbaum.

This is a rich and highly informative chapter that reviews the state-of-the art in neuroimaging of discourse functions. Note that the studies cited involve primarily healthy adult subjects, and the discussion is focused on studies that have specifically attempted to isolate particular cognitive and brain functions in discourse comprehension.

Mason, R.A., & Just, M.A. (2004). How the brain processes causal inferences in text. *Psychological Science*, *15*(1), 1–7.

Replicating previous findings from behavioral studies in an fMRI study, the authors show that (1) subjects are slower to encode inferences that are more distantly related to a particular outcome and (2) subsequent recall is strongest for causal inferences that are moderately related to the outcome sentence. The authors discuss these results in the context of a two-stage theory of inferencing, which posits separate processes related to inference generation and memory integration.

Readings related to Section 16.4: Right Hemisphere Contributions to Discourse Comprehension

Beeman, M.J., Bowden, E.M., & Gernsbacher, M.A. (2000). Right and left hemisphere cooperation for drawing predictive and coherence inferences during normal story comprehension. *Brain and Language*, *71*(2), 310–336.

This study provides important evidence on right versus left hemisphere contributions to discourse processing, using the divided visual field method. Results suggest a right hemisphere advantage in priming of forward (predictive) inferences, and a left hemisphere advantage in priming of backward (bridging) inferences. The authors relate these patterns to Beeman's right hemisphere "coarse coding" hypothesis.

Robertson, D.A., Gernsbacher, M.A., Guidotti, S.J., Robertson, R.R., Irwin, W., Mock, B.J., & Campana, M.E. (2000). Functional neuroanatomy of the cognitive process of mapping during discourse comprehension. *Psychological Science*, *11*(3), 255–260.

In an fMRI study the authors found greater right hemisphere BOLD activation for lists of sentences that used definite articles rather than indefinite articles to anaphorically relate the nouns in a text. These findings are particularly impressive, given that subjects were not instructed to try to make coherence links across the individual sentences that were presented on each trial.