

# **The Routledge Handbook of Discourse Processes**

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# The Cognitive Neuroscience of Discourse

## Covered Ground and New Directions

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Cognitive neuroscience and discourse processing are both young fields, yet their intersection has already produced a surprisingly rich body of results. In this chapter, we outline the major findings of past work and then describe some exciting new directions in discourse processing research. We begin with a discussion of the evolutionary origins of discourse processing, follow this with a discussion of the mechanisms of interest to neuroscientists who study discourse, and conclude with an overview of the new directions in which this work has recently begun to move. Our hope is to provide a useful overview of what neuroscience has to offer researchers interested in discourse, as well as to push the field forward by highlighting new methodological advances and what they have revealed.

### **Evolution and the Neurobiology of Language and Discourse**

The neurobiology of language is a wide scientific field, encompassing systems from insects to humans and levels of analysis ranging from neurotransmitter systems to multiple communicating organisms. Within humans, it encompasses both oral-gestural language and written language. Oral and gestural language resulted from the influence of natural selection over millions of years and comprises a species-general capacity that emerges in most humans without tutelage. Written language, in contrast, is a relatively recent cultural invention that only arises in the presence of deliberate instruction and practice. These differences have

important implications for the neurobiology of language. Most fundamentally, the neural mechanisms for oral and gestural communication are explained in terms of how they evolved from non-language abilities into language-specific functions, whereas writing systems must be explained by the co-option of mechanisms that evolved for other purposes.

Recognizing these evolutionary differences can be useful when theorizing about language and the brain. For example, the dual-stream account of auditory speech recognition proposes an account of how speech recognition evolved (Hickok & Poeppel, 2007). According to this theory, one route to recognizing spoken language builds on mechanisms involved in motor control. Regions in the lateral prefrontal cortex (IPFC) and the anterior-superior parietal lobe are important for goal-directed action in many species. These regions evolved to take input from the auditory cortex and map gestures (both heard and seen) onto motor plans. In other words, the perception of communicative gestures (both visual and auditory) depends on referencing the motor plans required to produce these gestures. This system now forms what is commonly referred to as the dorsal language comprehension stream. In most people, this system is located more in the left cerebral hemisphere than the right. This lateralization reflects the dorsal system's evolutionary roots in the motor control system, as the left hemisphere controls the right side of the body, which is dominant for action in most individuals. Over the same evolutionary time-course, a ventral language comprehension stream developed to map auditory features onto the semantic features of words. This stream involves projections from the auditory cortex posterior to the superior temporal gyrus (STG) and anterior to the inferior temporal sulcus (ITS) and middle temporal gyrus (MTG). These projection zones (STG, ITS, MTG) also receive converging input from the visual object recognition system, providing a locus for representing semantic features. This dual-stream model has received wide support, providing a parsimonious account for a large body of patient and neuroimaging data.

Whereas the dual-stream account of spoken language comprehension is based on evolutionary processes, accounts of visual word recognition rely on exaptation. One example is the recent debate over the visual word form area (VWFA), a region in the left inferior temporal lobe that is selectively activated during the viewing of words but not other visual stimuli (Dehaene, Le Clec'H, Poline, Le Bihan, & Cohen, 2002). Activity in the VWFA is modulated by many lexical features, including word frequency, length, and orthographic regularity (Yarkoni, Speer, Balota, McAvoy, & Zacks, 2008). Some have argued that this region evolved to process configural cues for complex visual stimuli such as faces and objects (McCandliss, Cohen, & Dehaene, 2003), but its processing is co-opted and reapplied during the long developmental process of learning to read. Counter to this, others have argued that there is no functional unit that is remodeled by learning to read (Price & Devlin, 2003). From this view, the VWFA is part of a processing stream that is sensitive to several features associated with words, but processes these features across stimuli with no special selectivity for words. Whereas the first account proposes that reading re-wires readers' brains, the second account denies this. But most importantly, both accounts agree that the brain regions undergirding language were fixed before written language was phylogenetically acquired.

Within the broad field of the neurobiology of language, the cognitive neuroscience of discourse is a much more focal subfield (Willems, 2015). The term "cognitive" tells us that we are dealing with the mechanisms of thought, rather than those of sensation, perception, or action. The word "discourse" indicates that we are concerned with the construction and use of language structures that span sentences, rather than being composed of single sentences or parts thereof. Work in this area has demonstrated that the neural mechanisms of language processing at the discourse level differ from those at the level of smaller language units.

In part, whereas discourse processing relies on low-level language processing, it also employs numerous other mechanisms that evolved to represent the structure of events in the world (and our reactions to them) rather than language processing *per se*.

## ***Mechanisms and Phenomena***

### *Predictive Processing*

As other chapters in this volume note, there is not a coherent unified theory of discourse processing in terms of computation and behavior. Thus, it is not surprising that we also lack a unified neurobiological theory of discourse processing. What we have at this point is a growing set of replicable phenomena that are suggestive of mechanisms, and descriptions of some of those mechanisms. One particularly robust finding is that language processing is predictive. Comprehenders of discourse continually make predictions about what is coming next in the language stream, monitoring the quality of those inferences by computing the error between what is predicted and what actually occurs. The occurrence of a prediction error produces changes in reading time and in the electrical activity of the brain, as measured by electroencephalography (EEG).

Two kinds of predictive processing errors have been well characterized, at both the discourse level and lower levels of language processing. The first prediction error is based in semantic processing. The classic paradigm involves presenting words that are semantically incongruous within a sentence context (Kutas & Hillyard, 1980). For example, if one reads the sentence “I like my coffee with cream and dog,” reading times for the final word, “dog,” will be high compared to that for a semantically congruous word such as “sugar” (Marton & Szirtes, 1988). EEG recordings show that the incongruous word elicits an increase in a negative-going evoked response potential (ERP) approximately 400 ms after onset; because of the timing and polarity, this potential is known as the N400.

The second kind of prediction error involves predictions about syntax. For example, if one was to read “The child throw the ball,” reading the word “child” induces a prediction that the verb will be singular. As a result, “throws” is predicted and encountering “throw” leads to a prediction error. This error once again results in a characteristic ERP, but one different from the N400 (Osterhout & Holcomb, 1992). In this case, the ERP peaks at around 600 ms and is positive-going; hence, it is known as a P600. In addition, behaviorally, syntactic violations lead to slowing on the word that produces the violation, but *speeding* on the sentence-final word. This is possibly because the language processing system has “given up” resolving the error (Ditman, Holcomb, & Kuperberg, 2007).

Although most studies of prediction errors examine violations at the level of the sentence, both semantic prediction (N400) and syntactic prediction (P600) effects have been observed in studies of discourse. For example, van Berkum and colleagues asked participants to read stories that set up a semantic expectation about a character or situation, which was then violated (van Berkum, Hagoort, & Brown, 1999). One story described an older sister that went to wake her younger brother but found him already dressed and ready to go. The target word was always congruous at the level of the individual sentence, but could either be congruous or incongruous at the discourse level. For example, after learning that the sister discovered her brother already dressed, participants read “Jane told her brother that he was exceptionally quick/slow.” Reading the unexpected word “slow” led to a larger N400 response. Similar results were also observed when the materials were presented aurally (van Berkum, Zwitserlood, Hagoort, & Brown, 2003).

An example of discourse-level syntactic prediction comes from a study by Knoeferle and colleagues (2008). In this experiment, participants viewed pictures with three characters and then listened to sentences describing the pictures. The pictures were deliberately silly, so that both the characters and the actions were easy to observe and name. For example, one of the pictures showed a pirate washing a princess, while the princess painted a fence. After viewing the picture, a sentence was presented that contained either a predictable verb (e.g., “The princess paints the fence”) or an unpredicted verb (e.g., “The princess washes the pirate”). Both sentences were syntactically appropriate at the level of the sentence, but one conflicted with the syntax of the action. These anomalies produced a P600 ERP, similar to what is observed for sentence-level syntactic violations.

### *Segmentation*

A second robust mechanism of discourse processing is segmentation. When people listen or read, they segment language into phonemes, syllables, words, clauses or phrases, and sentences. At the discourse level, sentences (or sometimes clauses or phrases) are assembled into larger units. For both written and spoken discourse, a critical kind of segmentation is the segmentation of the ongoing language stream into events.

One account of discourse-level segmentation is given by *event segmentation theory* (EST; Zacks, Speer, Swallow, Braver, & Reynolds, 2007). EST is a model of how comprehenders segment ongoing activity into events, not just for discourse but also during live perception of actions. Briefly, EST is rooted in the predictive mechanisms discussed in the previous section. It proposes that listeners and readers constantly make predictions about features of a discourse that are relevant for maintaining comprehension; features often include characters, objects, locations, time, goals, and causes. To make these predictions, EST proposes that comprehenders construct and update situation models (or “event models”) that maintain a representation of “what is happening now” (Kintsch & van Dijk, 1978; Zwaan & Radvansky, 1998). Event boundaries correspond to a cascade of processing in which the presence of increasing prediction errors leads to an updating of one’s situation model. Updating based on rapid increases in prediction error allows a comprehender to negotiate a balance between maintaining a situation model that is stable enough to be useful for prediction, but not so rigid as to produce perseverative errors. For example, reading that a new character has arrived reduces the predictability of a situation, and errors should occur. At this time it would be adaptive to update one’s situation model to incorporate information about the new character (cf. Rapp, Gerrig, & Prentice, 2001).

EST is closely related to two other cognitive theories of discourse processing. One is Gernsbacher’s (1990) *structure building theory*. In that theory, the mechanism of *shifting* to construct a new discourse representation is similar to the event segmentation mechanism proposed by EST. The other related theory is Zwaan’s (1999) *event indexing model*. From that model, EST borrows the idea that dimensions of experience in a situation described by discourse are monitored and represented in a situation model. EST’s proposal that updating results from prediction failure is one unique feature of the model. A second unique feature is that it proposes mechanisms with both neurophysiological and information-processing aspects. A key mechanism in the model is the signaling of prediction error spikes, which may be implemented by midbrain neuromodulatory systems including the phasic dopamine system (Zacks, Kurby, Eisenberg, & Haroutunian, 2011). The consequences of prediction error signals are proposed to include broad phasic responses in the neocortex corresponding to situation model updating. This has been observed for narrative

reading (Speer, Reynolds, & Zacks, 2007; Whitney et al., 2009) as well as for the viewing of visual narratives in movies (Zacks et al., 2001; Zacks, Speer, Swallow, & Maley, 2010; Zacks, Swallow, Vettel, & McAvoy, 2006). For example, Speer and colleagues (2007) asked participants to read a set of stories about a young boy while brain activity was measured with functional magnetic resonance imaging (*f*MRI). After the initial reading, the participants read the stories again and marked off boundaries between meaningful units. When readers' brain activity was time-locked to those boundaries, phasic increases were observed in the posterior parietal, temporal, and anterior occipital lobes bilaterally, and in right dorsal frontal cortex. In a set of behavioral experiments, it was found that the points in the narrative that readers identified as event boundaries were those points at which more features of the narrated situation were changing. This is consistent with EST's prediction that situation changes lead to prediction errors, which in turn lead to event model updating.

### *Situation Model Construction: dmPFC*

The construction of a situation model is itself an important mechanism of discourse comprehension. Going back to classic studies of sentence and story memory conducted by Bransford and colleagues, behavioral research finds that coherent discourse affords the construction of a mental representation, in turn supporting better comprehension and memory (Bransford, Barclay, & Franks, 1972; Bransford & Johnson, 1972). In terms of the neurophysiology of situation model construction, Zacks and colleagues (2007) proposed that situation models are a specialized form of working memory that are maintained primarily by subregions of the prefrontal cortex. Support for this idea comes from a study by Yarkoni, Speer, and Zacks (2008). In this experiment, participants read two sorts of paragraphs while brain activity was recorded with *f*MRI. The coherent paragraphs described coherent situations, excerpted from a larger narrative. Scrambled paragraphs included the same sentences, but with each sentence randomly assigned to a different paragraph. This manipulation controls language structure up to the level of the sentence, allowing for the isolation of situation model construction mechanisms. In the dorsomedial prefrontal cortex (dmPFC), reading coherent paragraphs produced an activity profile consistent with situation model building: activity increased at the onset of the paragraph and remained high. In contrast, the dmPFC showed no change in activity in the scrambled condition. Sustained activity in the story condition was also observed for regions in the lateral PFC and the cerebellum; these regions also showed smaller increases during the scrambled condition. In all of these regions, the level of activation in each block was correlated with subsequent memory for that block, which suggests that these regions contribute to the formation of stable long-term memories.

Early in the neuroscientific study of discourse processing, it was proposed that the right hemisphere is specialized for processing language at the discourse level—that is, for building situation models (Beeman, 1993; Robertson et al., 2000; St. George, Kutas, Martinez, & Sereno, 1999). This is an attractive proposal: Whereas the left hemisphere is specialized for language processing up to the sentence level in most right-handed adults (Hickok & Poeppel, 2007), perhaps the right hemisphere is specialized for language processing at the discourse level. This idea received early support from some neuropsychological studies (Beeman, 1993) and neuroimaging studies (Robertson et al., 2000; St. George et al., 1999). However, the right hemisphere hypothesis has not been supported by the bulk of subsequent work. Instead, meta-analyses identify a bilateral set of brain regions as being important for comprehension at the discourse level—particularly the dmPFC (Ferstl, Neumann, Bogler, & von Cramon, 2008; Mar, 2011). Focused studies have indicated that this

region is activated in circumstances that require integrating information across sentences (Ferstl & von Cramon, 2001, 2002; Kuperberg, Lakshmanan, Caplan, & Holcomb, 2006). For example, Yarkoni and colleagues found that when story paragraphs that allowed for discourse-level processing were directly contrasted to scrambled paragraphs that did not, the resulting activity was distinctly bilateral (Yarkoni, Speer, & Zacks, 2008).

### *Embodied Language Effects*

A phenomenon that has attracted considerable interest and debate in discourse comprehension is embodiment. In discourse, embodiment means using experience in one's body to understand a text. Pinning down exactly what that means has elicited some contentious debate (Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012; Wilson, 2002; Zwaan, 2014). The strongest and most interesting construal claims that we use modality-specific neural representations to comprehend language. Modality-specific brain regions obligatorily encode information about perceptual and motor dimensions such as spatial location (visual areas V1, V2, and others), color (visual area V4), and body part (primary somatosensory and motor cortex, and others). Much of the ongoing debate has concerned whether this claim is true and what sorts of evidence bear decisively on it.

Striking embodied language processing effects were first reported in behavioral studies of language processing. When people make judgments about sentences, they are generally faster when any accompanying nonlinguistic features are congruent with the language compared to when those features are incongruent. This is so even when the nonlinguistic features are irrelevant to the task being performed. (For reviews, see Barsalou, 2008; Fischer & Zwaan, 2008.) For example, Zwaan and colleagues (2002) presented readers with sentences such as "The ranger saw the eagle in the sky" or "The ranger saw the eagle in its nest," followed by a picture, and asked them to judge whether the picture depicted an object in the sentence. Judgments were faster when the picture showed the eagle in a pose that matched the sentence description, even though the shape of the eagle was not relevant to the task.

Neuroimaging studies of language comprehension have also provided evidence for embodied language processing, mostly in the motor domain. For example, Hauk and colleagues (2004) showed that making judgments about action words such as "pick," "lick," and "kick" led to localized activity within somatosensory and motor cortices that corresponded to areas involved with actual body movements (Hauk, Johnsrude, & Pulvermuller, 2004). An important question about such findings is whether they generalize to naturalistic discourse processing. Speer and colleagues (2009) tested this by measuring brain activity when specific dimensions of a narrative changed during a long story (Speer, Reynolds, Swallow, & Zacks, 2009). For example, in a classroom situation, reading "he crumpled the paper" is a change in the object acted on (i.e., paper), and reading "returned to her desk" signals a change in location. Changes in causes, characters, goals, objects, space, and time were all indexed. The authors found large cortical regions that responded to multiple changes, but also found many regions that responded selectively to a single type of change. For example, object changes selectively evoked activity in motor and somatosensory cortex that was lateralized to the hemisphere responsible for control of participants' dominant hands, which is suggestive of a modality-specific representation. To follow this up, Kurby and Zacks (2013) asked a new group of participants to rate each clause in these stories for the strength of the sensory or motor experience they evoked. They also had the new participants rate the paragraphs studied by Yarkoni and colleagues (2008). What they found was that high-imagery clauses—coded as visual, auditory, or motor—evoked localized responses in regions known to be specialized for these respective modalities.



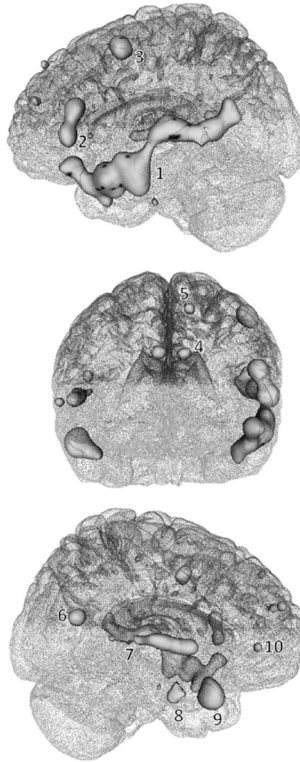
One critique of embodied language theories proposes that embodiment is epiphenomenal. Like the heat given off by a light bulb, it occurs along with the mechanisms that are responsible for comprehension, but is not itself causally involved in comprehension (Chatterjee, 2010; Mahon & Caramazza, 2008, 2009). Another critique argues that embodied effects reflect task demands or other artificial constraints during discourse processing tasks in the laboratory (Speer et al., 2009). At this point, the weight of the evidence seems to support the strong embodied language processing claim for the necessity of modality-specific regions for some kinds of language comprehension (Pulvermüller & Fadiga, 2010). However, it is clear that the degree to which reading and listening comprehension is embodied depends on the text, the task, and a reader's abilities and goals. When a skilled and motivated reader is immersed in a text and reading for deep comprehension, it is likely that perceptual-motor representations play a causal role in processing the discourse. However, when a reader is struggling or skimming a text, there may be little sign of embodiment.

### *Theory-of-Mind*

The last phenomenon we will discuss is theory-of-mind (ToM) or mentalizing, which involves the ability to infer another person's mental state(s). Cognitive neuroscience studies of ToM are inextricably tied with studies of discourse in part because the initial, influential, neuroimaging study of ToM involved reading stories about characters' mental states (Fletcher et al., 1995; for a recent study involving implicit mental inferences, see Kandylaki et al., 2015). This experiment found increased activity in the mPFC, posterior STS, temporal poles, and posterior cingulate (PCC) when participants attributed mental states to others, and this pattern has been consistently observed in subsequent studies (e.g., Gallagher & Frith, 2003). Two features of this neuroanatomy are important. First, it overlaps heavily with a network of regions that is highly active when participants lie quietly in the scanner, awake but with no fixed task, which has come to be known as the default network (Buckner, Andrews-Hanna, & Schacter, 2008; McGuire et al., 1996). Second, the most robust activation, in the mPFC, corresponds to the region we previously noted as associated with situation model construction.

A number of different studies have examined this overlap in the brain regions associated with discourse processing and those associated with theory-of-mind (e.g., Ferstl & von Cramon, 2002; Ferstl et al., 2008; Mason & Just, 2009, 2011). In a recent investigation, a series of meta-analyses were used to quantify the degree of overlap between discourse processing regions and mentalizing regions across a number of past studies (Mar, 2011). First, two separate meta-analyses were conducted on ToM: one for story-based studies and one for studies that employed other types of stimuli to isolate the mentalizing network. A comparison of brain regions implicated in both meta-analyses revealed a conservative estimate of the mentalizing network. These regions were then compared to the results of a meta-analysis of narrative-processing regions (see Figure 14.1). A number of the ToM areas were also implicated in the set of narrative-processing studies, including the mPFC, bilateral posterior STS and temporoparietal junction, bilateral anterior middle temporal gyri (just posterior to the temporal poles), and a small region in the inferior frontal gyrus. What these regions of overlap represent is open to interpretation. It could be that they support mentalizing about fictional characters while processing narratives, or it might be that some more basic process underlying both mentalizing and discourse comprehension is being represented by this network. In favor of the former possibility, one study found that a sub-network of the default network appears to be closely linked to mentalizing during reading, with follow-up analyses





*Figure 14.1* Meta-analytic results from Mar (2011) visualizing brain regions associated with narrative comprehension. Clusters include: (1) pSTS/TPJ, STS, STG, MTG, aTL, IFG; (2) IFG; (3) dorsal precentral gyrus; (4) bilateral mPFC; (5) mPFC/aSFG; (6) pSTS; (7) STG; (8) MTG; (9) aTL; (10) IFG. Additional clusters not visible; for full details see Table 7 of Mar (2011). For a color version of this figure, see <https://osf.io/jxdnw/>

supporting the idea that frequent reading could hone or improve mentalizing abilities (Mar & Oatley, 2008; Tamir, Bricker, Dodell-Feder, & Mitchell, 2016).

In sum, the cognitive neuroscience of discourse at this point has discovered a set of robust empirical phenomena and provided sketches of mechanisms to explain these phenomena, but has not yet offered up a comprehensive theory of discourse-level language processing in the brain. As we move toward such a theory, building on past work, the field is also growing in exciting new directions. It is to these new directions that we now turn.

## New Directions

Cognitive neuroscience continues apace to build on the studies of the past with the goal of developing a comprehensive theory of discourse processing informed by brain science. The field has expanded in exciting new directions, employing new research populations, broadening the aspects of reader behavior that are considered, and using innovative stimuli, methods, and analyses. As is to be expected, branching out in all these different ways often means that there are only one or two studies of a kind, rendering it difficult to knit these branches into a cohesive whole or draw firm conclusions regarding these topics. In light of

this, our main goal in reviewing these interesting new undertakings is to inspire and motivate further work in these promising directions, focusing on how these new paradigms can be adopted and adapted for future research.

### *Texts*

Cognitive neuroscience investigations of language processing focused initially on single words, moving only recently to sentences and connected discourse. For that reason, most early studies of discourse paid little attention to what type of text was being presented as the presentation of connected sentences was itself rather novel. However, neuroscientists have now begun to explore how different genres of texts are processed and received. Because this direction is rather new, it is especially difficult to draw conclusions regarding different types of texts. A majority of past studies of discourse have employed simple narrative texts. Although some researchers presented expository texts (e.g., Kansaku, Yamaura, & Kitazawa, 2000), this was often without providing any rationale for choosing this genre or acknowledging any possible genre effects. This has changed, with neuroscientists now increasingly sensitized to the importance of genre differences, reflecting past work by behavioral scientists (e.g., Zabrocky & Ratner, 1992). Swett and colleagues, for example, frame their own study of discourse as one that specifically investigates the neural correlates of comprehending expository text (Swett et al., 2013). To arrive at a clearer picture of how stories and exposition are differentially processed, however, it is necessary to present both types of text within the same study. An EEG study on inferencing did just this, presenting participants with narrative and expository passages of about four sentences in length (Baretta, Tomitch, MacNair, Lim, & Waldie, 2009). Few differences in brain activity were observed between genres, although the authors did find neural evidence that readers detected unpredicted and incongruent information more readily for the expository texts (as evidenced by a greater N400) compared to narrative texts. This is consistent with the behavioral data, which found that participants were superior at drawing inferences when reading the expository texts. In light of these demonstrated differences, future work on prediction might benefit from including different genres of text as stimuli.

Texts in the real world exist in far greater variety than simply being either narrative or expository in nature and bold researchers have begun to delve into these other genres. Zeman and colleagues, for example, conducted an *f*MRI study of responses to both poetry and prose (Zeman, Beschin, Dewar, & Sala, 2013b). The texts included practical as well as evocative prose passages, rather accessible as well as somewhat difficult sonnets, along with some poems that the participants selected themselves. The researchers found that a number of brain regions were similarly activated in response to both poetry and prose, perhaps not surprising since both involve discourse-level language processing. There were, however, some regions differentially activated by the two forms of text. Poetry led to greater activation in key memory regions (i.e., bilateral hippocampi) as well as the right temporal pole. Prose, in contrast, led to greater activation in a central information-processing hub (the PCC) as well as visual areas in the occipital lobe. When self-selected poetry was contrasted with the experimenter-chosen texts, greater activation was observed in the parietal lobes (bilaterally), likely reflecting the fact that participants knew these passages well and recognized them, reading them “by heart” rather than for the first time. The variety in the stimuli employed here is highly admirable and something that future studies will hopefully emulate. In particular, allowing the participants to choose some texts presents an intriguing design element, allowing for a clearer understanding of how personally meaningful texts are processed. This study

also included a unique element with respect to its target population, in that experts in the form of faculty and graduate students from an English department participated. Unfortunately, the data from these experts was not contrasted with naïve controls. This would have allowed for an exploration of how expertise interacts with discourse comprehension, an interesting question that remains to be answered.

In addition to different genres of text, there are also unique aspects within a text that deserve special interest. A single story can have moments that are evocative in different ways, with descriptions that make the reader laugh out loud at one point and experience crushing dread at another. One study by Lehne and colleagues examined an emotion that is rather unique to discourse: suspense (Lehne, Engel, Rohrmeier, Menninghaus, Jacobs, & Koelsch, 2015). Although single words and sentences can generate many of the basic emotions like happiness and sadness, building suspense relies upon a longer time-scale to create anticipation and is not easily achieved at lower levels of language. The creation of suspense is likely rooted in the construction of situation models for the story's plot and prediction in the form of anticipating the potential for a negative outcome (de Graaf & Hustinx, 2011). In the study by Lehne and colleagues (2015), the short story *Der Sandmann* (The Sandman) by E.T.A. Hoffmann was further shortened by experimenters and then portioned into 65 separate segments, to be read by participants who judged how suspenseful each segment was while being scanned using fMRI. Explicit ratings of suspense predicted activation in a number of different brain regions, many of which had previously been observed in past studies of narrative comprehension and social cognition (e.g., posterior STS, TPJ, mPFC; see Figure 14.1). This approach—breaking a longer text into many smaller segments and gathering rating data after each segment—provides a nice way of collecting behavioral data as participants read a lengthier text. Emulating this technique would help researchers to employ longer and more ecologically valid story stimuli in their designs. There are risks associated with this approach, however: Readers may find the constant need to provide ratings to be disruptive and the type of rating requested likely sensitizes readers to particular aspects of the text. That said, moving toward longer, more ecologically valid texts is key for the neuroscience of discourse and collecting explicit judgments to accompany neural data will always be valuable. Both would allow this neuroscientific work to be more easily integrated with behavioral research on discourse processes, allowing for more rapid development of cross-disciplinary models of discourse comprehension.

In addition to emotions, different texts can also engage the reader to varying degrees. Richard Gerrig (1993) described narrative engagement as transportation, employing a metaphor of the reader being transported into the narrative world. Some texts can be more or less successful in engaging readers. In a reanalysis of fMRI data from bilinguals reading emotional Harry Potter passages (Hsu, Jacobs, Citron, & Conrad, 2015a), an entirely separate group of readers rated how immersed they felt after reading each excerpt (Hsu et al., 2014). Immersiveness ratings were then related to the neural activity observed in the group of participants who read these same passages while being scanned with MRI. Activity in a region of the middle cingulate cortex was found to correlate more highly with immersion ratings for the fear-related passages compared to the neutral passages. This study illustrates how various qualities of a text can be associated with neural responses long after the fMRI data have been collected. Subjective responses to the text, like immersiveness or elicited emotion, can be assessed by separate groups of participants as may more objective text qualities like type-token ratio or average word frequency. These data can then be combined with neuroimaging data for analysis.

Fictional narratives contain a wealth of unique aspects, not limited to their potential to evoke emotions or engage readers. For example, there are no limits to what can be represented by a story, with characters, objects, and settings that are rarely or even never experienced in the real world commonly occurring. One research group conducted a fascinating study that highlights the potential to study these unique aspects of narrative, by examining the supernatural events within the Harry Potter series (Hsu, Jacobs, Altmann, & Conrad, 2015b). When brain activity elicited by supernatural excerpts was contrasted with activity observed during reality-consistent passages, a number of brain regions related to attention and emotion were found to be more strongly engaged (e.g., bilateral inferior frontal gyrus [IFG] and inferior parietal lobule [IPL], as well as the left amygdala). Future studies could take a similar approach with other types of narrative content, such as interactions with future technology or shifts in time in the form of flash-backs or flash-forwards.

The fact that fictional narratives can contain elements not found in reality is often a helpful way for us to distinguish fiction from fact. But things are not often so easy and another promising direction for research on discourse is how people make this distinction (Abraham, von Cramon, & Schubotz, 2008). One way in which we can identify a piece of text as representing fiction or reality is when it is explicitly labeled as one or the other. Altmann and colleagues examined this very question, by presenting different participants with identical short narratives that were labeled as either “real” or “invented” (Altmann, Bohrn, Lubrich, Menninghaus, & Jacobs, 2014). In this way, differences in brain activity for the two conditions can be inferred to result from the expectations surrounding a text based on its purported source, rather than the actual words being read (which were identical for both conditions). Some brain regions were more active when texts were labeled as fiction (e.g., frontal poles, mid-line areas throughout the cingulate and precuneus), whereas other regions were more active when texts were presented as factual (e.g., temporal pole, cerebellum, left MTG/STG). These researchers associated the fiction expectation regions with the fronto-parietal control network and the default network, conjecturing that an expectation of fiction results in a more flexible situation model that invites imagination about what may have been. This labeling of a text, as invented or real, is known as paratextual information, or information about a text. Other examples of paratextual information include whether a story is written by a man or woman, whether a text is critically acclaimed or universally panned, and whether a text has been translated from a foreign language. The potential influences of these other forms of paratextual information have been investigated with behavioral paradigms and it would be interesting to see more neuroscience work on these kinds of questions.

### *Populations*

In addition to expanding the purview of what texts are studied with cognitive neuroscience, researchers have also begun to better appreciate that interesting differences may be occurring across different types of readers. This mirrors advances in behavioral research on discourse processing, many of which are outlined in Chapters 8 and 9. Within neuroscience, one approach to studying different types of readers has been to examine the discourse processing abilities of people with neurological and psychiatric disorders. For example, researchers have used narratives to delineate the language capacities of individuals with amnesia (Zeman et al., 2013a), schizophrenia (Marini et al., 2008), and autism (Barnes, 2012). A related approach involves studying special populations to better understand how specific brain regions support discourse processes. An obvious example involves

studying the performance of lesion patients to identify which brain regions are necessary and/or sufficient for narrative processes (Mar, 2004). Continuing along this line of research are investigations into how the neural correlates of discourse processing might differ for special populations compared to typically developing ones (e.g., individuals with autism; Mason, Williams, Kana, Minshew, & Just, 2008; Williams et al., 2013).

In addition to studying special populations, researchers are becoming increasingly curious about individual and group differences within typically developing language users. For example, it is a well-recorded fact that numerous gender differences exist with respect to reading. A 2009 survey of 65 countries found that girls outperform boys in reading ability for every single country examined (OECD, 2011). In addition, there have been a number of studies demonstrating neural differences between men and women with respect to lower-level language processing, such as at the word or sentence level (e.g., Burmann, Bitan, & Booth, 2008; Clements et al., 2006; Pugh et al., 1996; Shaywitz et al., 1995; cf. Wallentin, 2009). But what about gender differences in the processing of discourse?

An early *f*MRI investigation into gender differences for discourse comprehension presented auditory versions of short essays to men and women, with the same audio presented in a reversed form as a control (Kansaku, Yamaura, & Kitazawa, 2000). When listening to the essays, men exhibited more left-lateralized activations (around the superior and middle temporal gyrus, relative to the control condition), whereas women exhibited more bilateral activations (in approximately the same areas). In a follow-up study, the researchers compared chopped-up versions of these essays to their reversed counterparts and observed no such differences in lateralization between men and women. This led the researchers to conclude that the lateralization differences in posterior language areas observed for men and women are specifically tied to the processing of coherent narratives. Unfortunately, the use of reversed language as a control is less than ideal, as the resulting contrast does not isolate the unique contributions of discourse-level language; there are too many differences between the experimental and control stimuli to draw meaningful conclusions from the contrast (e.g., simple meaningfulness at the word level). Meaningful, but sentence-level, language is the most appropriate control condition to isolate processes specific to discourse.

Meaningful sentences were employed as a control in an imaging study on gender differences in discourse comprehension by Frank and colleagues (Frank, Baron-Cohen, & Ganzel, 2015). These researchers presented men and women with a series of very simple stories to read in the scanner, and contrasted these images with those resulting from the reading of very similar unlinked sentences. They found few differences in activation between men and women. The sole difference was that women deactivated a region within the right ventromedial PFC more so than men. Regrettably, both of these studies likely suffered from low statistical power (Button et al., 2013), as neither included more than 30 participants per group. (Assuming an average effect-size of  $d = .5$  and 80% power, 64 participants per group is required for a simple two-tailed *t*-test.) This means that there is a high risk of false negatives and so a failure to detect differences is somewhat difficult to interpret. Although there are very real economic hurdles to collecting adequate sample sizes for neuroimaging research, higher statistical power should be a future goal of work in this area (Mar et al., 2013). A future study, with greater power, may well answer the question of whether differences exist between men and women in how situation models are constructed and updated.

Another interesting population for the study of discourse is bilingual (or multilingual) individuals. Although past work has determined that for those highly proficient in their second language there are few differences in brain activation when processing words or sentences in either language (Fabbro, 2001), what about responses to stories? Hsu and



colleagues asked Germans also proficient in English to read four-line passages from the Harry Potter books that were either emotional in tone (happy or fearful) or neutral (Hsu et al., 2015a). These excerpts were also presented in either German or in English. Using the neutral passages as a control, happy passages presented in the participants' native tongue (German) elicited more activation in key emotion areas of the brain (i.e., the amygdala, bilaterally) as well as a portion of the precentral gyrus, compared to the same contrast in their second language. In other words, first-language processing of happy passages selectively increased activation in these areas relative to second-language processing of happy passages. No such interactions were found for the fearful passages. Additional analyses confirmed that passages read in a second language resulted in an attenuated emotional response, though readers were highly proficient at reading in that language. By taking a long, naturalistic text and breaking it down into specific excerpts associated with particular aspects of interest (i.e., certain emotions), the researchers were able to achieve several notable aims: (1) employing a naturalistic stimulus in the form of a professionally written long-form narrative, (2) highlighting key components of this text by excerpting portions, thereby (3) creating a stimulus set appropriate for a neuroimaging study.

Across both special and normally developing populations, individuals can also differ with respect to experience or trait tendencies, and these differences may be associated with different neural responses to discourse. For example, behavioral studies have established that personal experience with the topics addressed in a piece of fiction can affect how that text is processed (Bartlett, 1932; Green, 2004). Having personal experience with a situation described in a text might lead the reader to resonate more with the content, perhaps allowing him or her to better imagine what it would be like to see or do something similar. In a neuroimaging study investigating this possibility, Chow and colleagues asked whether experience with a topic would result in more coherent brain activity when reading a story about that same topic (Chow, Mar, Xu, Liu, Wagage, & Braun, 2015; for a related study on familiarity with the topics of nonfiction essays, see Buchweitz, Mason, Meschyan, Keller, & Just, 2014). To test this, the authors first pilot-tested story topics to identify those with which participants would have varying levels of experience, such as performing a musical piece in front of an audience. They then wrote short three-paragraph stories around these topics, with certain paragraphs designed to focus on either perceptual content (i.e., visually vivid details) or action content (i.e., movements and physical behaviors). Coherence of brain activity was measured in the form of correlations within the brain networks responsible for visual and motor processing. Individuals who reported more personal experience with the topic of the story had more tightly correlated activity in the visual network while reading visually vivid details. Similarly, when reading about actions, those with more experience exhibited higher correlations within the motor processing network. These results suggest that the degree to which language processing is an embodied process depends in part on our level of past experience with what's being represented.

There are several noteworthy aspects to this study that could be applied to future investigations of discourse processing. For one, pilot-testing was employed to maximize the variability in responses, helping to compensate for the small sample size; small samples are a common and nontrivial problem for correlational analyses in neuroimaging (Mar, Spreng, & DeYoung, 2013). Second, the texts for this study were carefully prepared to capture both variability in experience as well as the processing of either visual details or motor actions. These details and actions were described over the course of several sentences to allow for a block of neural activity to be isolated for the analysis of correlations within brain networks. Methods such as these could easily be adapted to explore other characteristics of readers



(e.g., levels of reading ability; Prat, Mason, & Just, 2011, 2012) and different aspects of texts using neuroimaging (e.g., emotional segments, instances of free indirect discourse).

Individual readers not only differ from one another with respect to their personal experiences, but also in trait tendencies closely related to literary discourse. For example, people differ in their tendency to become highly absorbed or transported into fictional narratives. Although we have previously discussed how different texts can differ in their ability to engage readers, people also differ in their natural tendencies to become engaged regardless of the text. One oft-used measure of trait empathy includes a subscale closely related to transportation: the Fantasy subscale of the Interpersonal Reactivity Index (IRI; Davis, 1980). All but one of the seven items in this subscale describes a tendency to become absorbed in books, movies, and television. In a study examining how scores on the IRI relate to differences in brain structure, the Fantasy subscale was found to predict greater gray matter volume in a portion of the right dlPFC (Banissy, Kanai, Walsh, & Rees, 2012). One of the most impressive aspects of this study was its large sample size, with data from 118 individuals being included. Future research on this topic would benefit from a multi-dimensional approach to measuring trait tendencies toward transportation, distinguishing emotional engagement from attentional focus, for example (Busselle & Bilandzic, 2009).

A tendency to become highly engaged or transported into a narrative world is highly related to the construct of character identification (Tal-Or & Cohen, 2010). Character identification is unlikely to emerge in the context of single sentences and cannot occur for discourse that lacks characters. As a result, identifying with fictional characters is relatively unique to literature and a ripe topic for investigation for cognitive neuroscientists interested in discourse. In a study on this topic, Cheetham and colleagues employed a German version of the IRI that includes the four positively worded items of the Fantasy subscale, isolating those that relate to character identification (Cheetham, Hänggi, & Jancke, 2014). Employing a similar approach to the previous study on transportation, but with a smaller sample, they found that cortical thickness varied with self-ratings of character identification for areas in the left dmPFC (negatively) and IFG (positively). The volume of a region in the left dlPFC was also positively related to these scores.

These two studies of trait transportation and character identification illustrate the potential to examine how self-reports of tendencies related to discourse processing can be related to structural MRI data, such as brain volume and cortical thickness. The method could also be extended to other forms of neural data, such as resting-state connectivity analyses and white-matter organization (i.e., diffusion tensor imaging; DTI). One important factor to keep in mind with these approaches, however, is the importance of sample size and statistical power when examining correlations.

### *Reader Response*

Although it is true that different types of individuals may react differently to a text, a single text can also evoke a variety of reactions among individuals belonging to a similar population of readers. Examining the variability in how readers respond to a text is yet another fertile area of inquiry for cognitive neuroscientists interested in discourse.

One subjective response that seems ripe for investigation is how the brain reflects varying levels of engagement or immersion in a narrative text. Studies examining narrative engagement have previously been discussed based on trait tendencies or as a quality of the text, but no study to date has examined evaluations of immersion by readers also providing neural

data, with transportation measured either *in vivo* or directly after reading. Hopefully this gap in the literature will be filled in the near future.

For a successful example of investigating variability in reader responses for a single population, one need only look to the previously discussed study on poetry and prose (Zeman et al., 2013b). In this study, readers reported their evaluations of the texts, including each text's emotionality and literariness. Both are subjective responses to a text, with emotionality being familiar to lay readers and literariness an elaborated construct for this population of literary scholars. Drawing on past neuroaesthetic work on music that elicits "shivers down the spine" (Blood & Zatorre, 2001), a similar network of brain regions was found to track with increasing ratings of emotionality: the thalamus, anterior cingulate, insula, cerebellum, and supplementary motor area (SMA). For literariness, higher ratings were associated with left-hemisphere regions and parts of the basal ganglia. These regions are components of the dorsal speech comprehension pathway described above, which is specialized for analyzing the sequential structure of language (Hickok & Poeppel, 2007). One possibility is that the processing of more literary texts taxes these components more heavily. To adopt this paradigm for future studies, almost any type of reader response or evaluation could be studied in this way and there exist a great number of possibilities still outstanding. Neuroaesthetics, for example, has explored beauty judgments for several kinds of stimuli (Skov & Vartanian, 2009), but not for literary discourse (e.g., Blood & Zatorre, 2001; Cupchik, Vartanian, Crawley, & Mikulis, 2009; Kawabata & Zeki, 2004; cf. Jacobs, 2015). Perhaps the closest example that exists involved participants reading single-line proverbs and rating them for beauty after leaving the scanner, with implicit aesthetic judgments associated with areas of the brain linked to reward (Bohrn, Altmann, Lubrich, Menninghaus, & Jacobs, 2013). But beauty can also be found in longer passages and it would be informative to learn if these responses were similar or different to finding beauty in visual art forms or music.

Measuring different responses to a text and associating these responses with neural data is one approach to studying variability in reader responses; another is to study the variability in the neural responses themselves. This latter approach was taken in an *fMRI* study by Nijhof and Willems (2015), who had participants listen to three short stories, with reversed versions of these stories serving as a control. For each story, sentences dealing with either actions or mental inference were identified. The authors observed great variability in the degree to which action-processing and mentalizing brain regions were activated during reading (identified using localizer tasks), with a negative correlation emerging across the group. In other words, the participants that tended to activate mentalizing regions more while reading the passages were less likely to activate action-processing areas, and vice versa. The researchers interpreted these data as demonstrating variability in reader responses at the neural level. It would be interesting to relate this variability in network activations to other reading outcomes or responses, such as immersion, identification, comprehension, recall, event segmentation, or perhaps the updating of situation models.

Responses to a text are not only subjective, but can also be evaluated objectively such as with comprehension and memory. Comprehension and recall for text material is linked to the ability to focus on the text material and not be distracted by unrelated thoughts. To explore how the two relate, Yarkoni and colleagues recorded brain activity while participants read narrative paragraphs, and then tested verbatim memory and comprehension for those paragraphs (Yarkoni, Speer, & Zacks, 2008). Better subsequent memory was associated with greater activation in the regions that were selectively engaged by a coherent discourse structure. This suggests that successfully constructing a situation model supports performance on later tests of comprehension and memory.

To construct, maintain, and update a coherent situation model, one must avoid distraction from unrelated thoughts. The effects of such distraction were also investigated in another study that asked participants to read excerpts of a nonfiction book, rate their own level of distraction, and then complete a series of comprehension questions (Smallwood et al., 2013). In an entirely separate session, a subset of these participants was scanned at rest with fMRI and inter-correlations between active brain regions were employed to form a resting-state functional connectivity analysis (rs-fcMRI; Biswal et al., 1995). Distraction or mind-wandering has been linked to the default mode network, which tends to readily emerge from rs-fcMRI data (Mason et al., 2007). Smallwood and colleagues (2013) found that connectivity between a key region of the default network, the PCC, and other brain regions was modulated by comprehension. Individuals exhibiting greater comprehension across the texts had stronger links between the PCC and right anterior insula while lying at rest. Worse comprehension was associated with stronger links between the PCC and the ventral striatum/amygdala. This study demonstrates that reader responses measured at one time can be meaningfully related to neural data collected on a separate occasion, even when that neural data is not tied to reading of any task at all.

### *Conversation*

Most work in the cognitive neuroscience of discourse has studied solitary participants comprehending a fixed text. But a great deal of real-world language use involves conversation—a dynamic interchange among two or more partners (Hasson, Ghazanfar, Galantucci, Garrod, & Keysers, 2012) that takes place within a complex social interaction fundamentally different from classic laboratory paradigms (Schilbach et al., 2013). Researchers are increasingly taking on the dynamic complexity of conversation, producing more ecologically valid investigations of language production and comprehension.

In everyday conversation, much of significance is never spoken but is only implied. Jang and colleagues investigated the neural basis of comprehending conversational implicatures, specifically focusing on those that violate the Gricean maxim of relevance (Jang et al., 2013). Participants observed an exchange between two speakers, with the first asking a question (e.g., “Have gas prices gone up a lot?”) and the second providing an answer that required either an explicit inference (“Prices have gone up a lot”), a moderately implicit inference (“I am saving gas nowadays”), or a highly implicit inference (“My dad takes the bus these days”). Participants then indicated if the answer meant “yes” or “no.” Comprehension of moderately and highly implicit answers, as compared to explicit answers, showed greater activation in the anterior temporal lobe (ATL), angular gyrus (AG), and posterior middle temporal gyrus (MTG), all left lateralized. When highly implicit answers were compared to moderately implicit ones, there were increased activations in all of these regions, in addition to unique activation in the left inferior frontal gyrus (IFG), left medial prefrontal cortex (mPFC), left PCC, and right anterior temporal lobe (ATL). Interestingly enough, activation in many of these areas is also observed in studies of reading narrative texts, perhaps reflecting the predictive inferencing that occurs during both types of discourse processing.

Bašnáková, Weber, Petersson, van Berkum, and Hagoort (2014) investigated implicature in a slightly richer social context. Participants were introduced to a speaker and a listener, and then heard a four-turn dialogue. The first two utterances established the communicative context and the final two utterances were a question and an answer. Depending on the preceding context, the answer (e.g., “It is hard to give a good presentation”) could be interpreted as either a direct reply to the question (“Is it hard to give a good presentation?”),

an indirect-informative reply requiring an inference (“Will you give a presentation?”), or an indirect-emotional reply requiring an inference (“Did you find my presentation convincing?”). Thus, unlike the study by Jang et al. (2013), the same answers served as direct or indirect replies based on prior context. Relative to direct replies, indirect replies activated a common set of frontal regions including dmPFC, bilateral superior medial frontal gyrus, the right SMA, and parts of the bilateral IFG, extending into the insula in the left hemisphere, as well as right TPJ and right middle temporal gyrus.

Recent neuroimaging studies have begun to map the neural mechanisms underlying the coordination of speakers and listeners in naturalistic conversation. Stephens, Silbert, and Hasson (2010) used *f*MRI to compare the time courses of neural activity for speakers and listeners. In most brain regions that shared activation for listeners and speakers, the listeners’ brain activity also displayed temporal coupling with a few seconds of delay, suggesting that the speaker’s discourse causally shapes the brain activity of the listener. Coupling occurred in brain areas associated with auditory and facial motor processing, as expected, but also throughout brain networks associated with language processing and beyond. Interestingly, in brain regions including the dlPFC and dmPFC, activity in the listener preceded that of the speaker. This finding supports the significance of predictive processing for language comprehension. In particular, the fact that these effects were prominent in the PFC and the fact that the degree of coupling predicted the degree of listeners’ comprehension suggest that listeners may construct a situation model that enables prediction, in line with our earlier discussion. Also of note, the coupled areas were highly bilateral, supporting the view that discourse comprehension is a bilateral rather than right-lateralized function. In a subsequent study, the same research group coached speakers to tell a once-spontaneous story repeatedly (Silbert, Honey, Simony, Poeppel, & Hasson, 2014). The original storyteller repeated the story multiple times, and other tellers learned it as well. The regions previously found to correlate between speaker and listeners also correlated across multiple retellings of the story, both within and between speakers.

One study has used simultaneous *f*MRI recordings of two people engaged in a live conversation to track coordination in truly spontaneous conversation (Spiegelhalder et al., 2014). Activity in the speaker’s motor cortex was found to predict activity in the listener’s auditory cortex. In this study, the broader coupling reported by Stephens and colleagues was not found, but this could reflect the lower statistical power of the study by Spiegelhalder and colleagues (2014). The degree of coupling between speaker and listener has been found to vary as a function of the discourse environment, with, for example, more rhetorically powerful speeches resulting in more coherent brain synchrony (Schmälzle, Häcker, Honey, & Hasson, 2015).

Although these studies clarify the neural bases of conversation, they fall short of fully approximating naturalistic conversation in important ways. Perhaps most obviously, all have retained the classic distinction between a speaker and listener, in which the speaker essentially produces an uninterrupted monologue and the listener acts as passive receiver, with no conversational turn-taking. This is due to the practical difficulties of producing interactive scenarios in an MRI scanner, and the complexity of disentangling and analyzing components of multifaceted behavior. However, there have been interesting developments on this front. In the first study of its kind, Derix and colleagues performed *post hoc* analyses of electrocorticography (ECoG) data recorded from pre-surgical epilepsy patients (Derix, Iljina, Schulze-Bonhage, Aertsen, & Ball, 2012). Based on the patients’ electrode placement and common behavior, the authors were able to compare activity in the temporal lobe as patients freely conversed with their life partners as compared to physicians. The authors

found that alpha and theta bands in the bilateral TP and entire ATL showed increased power when participants talked to life partners relative to physicians, although some electrodes in the posterior left ATL also showed higher power when talking to physicians. This study shows that non-experimental studies and *post hoc* analyses may be a promising way of investigating the neural basis of unscripted real-world conversation.

How we might develop better methods to explore naturalistic conversation is an important question for future research. One exciting direction is to simultaneously measure, or “hyperscan,” the brain activity of two or more people engaged in conversation. Over a decade ago, Montague et al. (2002) demonstrated hyperscanning in MRI, and others have since demonstrated the method using magnetoencephalography (MEG) and EEG (for a review, see Babiloni & Astolfi, 2014). To the best of our knowledge, with the exception of the study by Spiegelhalder et al. (2014) noted above, no study has yet employed hyperscanning to investigate real-time conversation. This is unfortunate, because it is presently unclear if the neural dynamics of conversation differ from what is suggested by studies that isolate production and comprehension. On the basis of recent neuroscience investigations of interpersonal, nonverbal communication, it seems possible—and we think likely—that interactive conversation will bear a neural signature distinct from that of simple comprehension and production. For example, in a study of gaze behavior, Saito et al. (2010) found that brain-to-brain coupling is greater when participants follow another’s gaze toward a target, rather than obey an instruction to do so. Similarly, in a study of hand gestures, Dumas, Nadel, Soussignan, Martinerie, and Garnero (2010) found that brain-to-brain coupling is greater when participants spontaneously started and ended a movement simultaneously. Although the reasons for the lack of uptake of hyperscanning are several and too lengthy to be discussed here (see Hari & Kujala, 2009, for a review), we think it will play a crucial role in future neuroscience studies of conversation.

### *Advanced Neuroimaging Designs*

As the preceding section indicates, one source of excitement in the cognitive neuroscience of discourse is the development of new neuroimaging methods. For example, some studies have paired neuroimaging with a longitudinal design, an impressive feat in light of the cost of the former and the threat of attrition associated with the latter. One group that managed to overcome these hurdles, led by Szaflarski (Szaflarski et al., 2012; see also Horowitz-Kraus et al., 2013) recruited 30 children between the ages of five and seven, and scanned them each year for up to 10 years. During scanning, the children listened to simple stories of around 30 seconds in length, with random pure tones presented as a control. As the children aged, the researchers witnessed an increased involvement of middle and superior temporal areas during story comprehension, even after controlling for anticipated confounds such as IQ and linguistic abilities. These increases demonstrate that the lateral temporal parts of the language processing network continue to mature bilaterally over this age span, perhaps reflecting a growth in semantic networks. Relative decreases during story comprehension associated with maturation were observed in the PCC and cuneus, as well as regions of the occipital cortex. The meaning of these decreases is less clear, but it could be tied to greater activity during the control condition over time as the resting-state control might be more likely to promote spontaneous thought. This impressive study brings us closer to understanding how the processing of narrative texts develops over childhood. Another longitudinal study of narrative processing involving adults (both participants with schizophrenia and controls) found that the neural activity elicited by a story-listening task



is highly stable within individuals across a period of 21 months (Maïza et al., 2011). This stability in activation provides an important baseline reference when examining longitudinal effects. Knowing that story-listening activations in adults are reproducible over relatively long periods of time allows for changes observed across a longitudinal study to be attributed to changes within the individual (e.g., treatment, experience, learning) and not low test-retest reliability. Together these two studies demonstrate that longitudinal neuroimaging research on discourse processes is certainly possible, opening the door for fascinating future work.

A rather unique type of longitudinal neuroimaging study was undertaken by Berns and colleagues, who wanted to know how reading a novel would affect functional connectivity in the brain (Berns, Kristina, Prietula, & Pye, 2013). They acquired a resting-state scan of 21 individuals every day for 19 days in a row, with the initial five days of scanning serving to establish a baseline control (i.e., “wash in” period) and five days at the end serving to examine the timeline of any effects post-reading (i.e., “wash out” period). For the nine days in the middle, participants read 1/9th of a novel (*Pompeii: A Novel*, by Robert Harris) prior to being scanned while at rest. A network of regions within the cerebellum showed significantly more connectivity after reading the entire novel. On the days when participants read the novel, three separate networks became more tightly connected, including one that involved the left angular gyrus, precuneus, and mPFC. This highly innovative approach to studying discourse achieved what not too long ago seemed like an impossible feat: studying the reading of an entire novel with neuroimaging. This success was achieved by two main methodological decisions: (1) breaking the novel into nine parts, and (2) not scanning participants as they read, but rather while they lay at rest after reading. The latter certainly raises the question of whether one is studying the process of reading a novel or rather studying a person who is thinking about parts of a novel that have recently been read (which is distinct, but not uninteresting). As pragmatic decisions are made to adapt reading paradigms for neuroimaging methods, it is important to examine how the questions being asked are also altered. Limitations aside, one could imagine modifying this paradigm to examine all kinds of related questions, such as comparing the reading of fiction to nonfiction, and reading something new to re-reading a familiar book.

Another novel methodology that has been applied to the neuroscientific study of discourse involves building computational models based on neuroimaging data. Wehbe and colleagues, for example, scanned nine individuals as they read an entire chapter of a Harry Potter book, presented one word at a time (using rapid serial visual presentation), over the course of 45 minutes (Wehbe, Murphy, Talukdar, Fyshe, Ramdas, & Mitchell, 2014). They then took this fMRI data and trained a computational model to predict the observed brain activity based on 195 different features of the text. These features included syntactic, semantic, and narrative information about the current state of the text (e.g., characters, actions, emotions, dialogue), updated with every new word. After training, the computational model achieved above-chance accuracy for classifying which of two novel passages was being “read” based solely on observed neural activity (74% correct, with 50% representing chance). The researchers were then able to isolate story features and identify the brain areas associated with processing different aspects of a text. Dialogue between characters, for example, was processed in bilateral temporal and inferior frontal areas, along with the right TPJ. Strikingly, these regions show some overlap with those identified in the study on conversation by Bašnáková and colleagues (2014). Given the richness of both neuroimaging data and discourse, employing computational network models seems to be a promising way to take a bottom-up approach to identifying relations between the two, possibly resulting in new hypotheses that can be pursued with more theoretically informed study designs.



## Conclusion

Surveying this terrain, we are encouraged by the rapid progress that has been made in the cognitive neuroscience of discourse. When the first edition of this handbook on discourse processes was being prepared 15 years ago, it was perfectly reasonable to omit consideration of neuroscience approaches. Now there is enough to say that we have had to be highly selective in our treatment and we can point to books that devote many or all of their pages to this topic (Hickok & Small, 2015; Schmalhofer & Perfetti, 2007; Willems, 2015). However, it is clear that this is early in the journey. We think the next 15 years will likely be characterized by two trends. First, we expect the field to look back at the path traveled thus far, sort through the phenomena we have described (and doubtless a few we have missed), separate the replicable wheat from the false positive chaff, and consolidate what remains into coherent mechanistic theories. In what we have described in the latter sections of this chapter, it is important to emphasize that these investigations are in their early stages and will likely be revised as more data are collected. Second, we expect that new neuroimaging and neurostimulation methods will allow the field to carve bold new paths. Three neuroimaging developments that we are particularly excited about are sophisticated time-series analysis (evident in the Conversation section above), machine learning methods that will help illuminate how patterns in brain activity map onto mental representation (Kriegeskorte, Goebel, & Bandettini, 2006; Norman, Polyn, Detre, & Haxby, 2006), and the use of computational models to predict moment-by-moment changes in neural activity. All in all, we have ample reason to hope for a very exciting future for the cognitive neuroscience of discourse processes.

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