Reilly, J., Losh, M., Bellugi, U., & Wulfeck, B. (2004). "Frog, where are you?" Narratives in children with specific language impairment, early focal brain injury, and Williams syndrome. *Brain Lang, 88*, 229–247.
Rogalski, E., Cobia, D., Harrison, T. M., Wieneke, C., Thompson, C. K., Weintraub, S., & Mesulam, M. M. (2011). Anatomy of language impairments in primary progressive aphasia. *J Neurosci, 31*(9), 3344–3350.
Rohrer, J. D., Rossor, M. N., & Warren, J. D. (2010). Syndromes of nonfluent primary progressive aphasia: a clinical and neurolinguistic analysis. *Neurology, 75*(7), 603–610.
Rosen, H. J., Gorno-Tempini, M. L., Goldman, W. P., Perry, R. J., Schuff, N., Weiner, M., . . . , Miller, B. L. (2002). Patterns of brain atrophy in frontotemporal dementia and semantic dementia. *Neurology, 58*, 198–208.
Sajjadi, S. A., Patterson, K., Arnold, R. J., Watson, P. C., & Nestor, P. J. (2012). Primary progressive aphasia: a tale of two syndromes and the rest. *Neurology, 78*(21), 1670–1677.
Scarna, A., & Ellis, A. W. (2002). On the assessment of grammatical gender knowledge in aphasia: the danger of relying on explicit, metalinguistic tasks. *Lang cogn processes, 17*(2), 185–201.
Scott, S. K., & Wise, R. J. (2004). The functional neuroanatomy of prelexical processing in speech perception. *Cognition, 92*(1–2), 13–45.
Troiani, V., Fernandez-Seara, M. A., Wang, Z., Detre, J. A., Ash, S., & Grossman, M. (2008). Narrative speech production: an fMRI study using continuous arterial spin labeling. *Neuroimage, 40*(2), 932–939.
Williams, G. B., Nestor, P. J., & Hodges, J. R. (2005). Neural correlates of semantic and behavioural deficits in frontotemporal dementia. *Neuroimage, 24*, 1042–1051.
Wilson, S. M., Galantucci, S., Tartaglia, M. C., & Gorno-Tempini, M. L. (2012). The neural basis of syntactic deficits in primary progressive aphasia. *Brain Lang, 122*(3), 190–198.
Wilson, S. M., Henry, M. L., Besbris, M., Ogar, J. M., Dronkers, N. F., Jarrold, W., . . . , Gorno-Tempini, M. L. (2010). Connected speech production in three variants of primary progressive aphasia. *Brain, 133*(7), 2069–2088.

4 Situation models in naturalistic comprehension

Christopher A. Kurby & Jeffrey M. Zacks

Abstract Reading a discourse often leads to the construction of a situation model – a mental representation of the state of affairs described by the text. Situation model construction is associated with specific behavioral and neural markers. In this chapter, we consider the following questions: How does reading that involves constructing a situation model differ from other kinds of reading? Do the behavioral and neurophysiological data support a distinction between incremental updating of situation model components and global updating by abandoning an old situation model to form a new one? Do situation models represent information about sensory and motor features in analog representational formats during normal reading for comprehension? The available results indicate that specific mechanisms underlie different forms of situation model updating, that situation model-based reading is qualitatively different from reading without forming situation models, and that readers routinely deploy perceptual and motor representations to understand features of the situations described by a narrative.

Reading is a cognitive tour de force. Just guiding the eyes to focus on the right part of the text at the right time is exquisitely complex (Rayner, Raney, & Pollatsek, 1995). Readers do this effortlessly, and also recognize complex patterns to identify letters, words, and larger units of text, parse strings of words into sentences, and recognize the meanings of words and sentences. However, to us the most striking thing about what happens when people read narrative texts is that they seem to transmute black marks on paper into vivid representations of hypothetical worlds – flashing armor and clinking swords or storming skies over sinking ships (Graesser, Golding, & Long, 1991). How does a reader accomplish such a feat? In this chapter, we focus on two more specific questions about the representations that readers construct when comprehending narratives: "How does a reader build up a representation of meaningful events from a linear string of words?" and "How are perceptual and motor features of experience captured in the representations the reader constructs?" Our account builds on a larger body of research on the construction of *situation models* in language comprehension. We will start with a brief introduction to situation models. (For a more extended review, see Radvansky and Zacks (2014).)

Situation models

When people read narratives, they tend to simultaneously develop at least three types of mental representations (Kintsch, 1998; van Dijk & Kintsch, 1983). Readers can come away from a story with an unembellished memory for the exact words and syntax. This is typically called the *surface form* (Kintsch, 1998). This is the type of memory tapped when one tries to recall the exact words (usually unsuccessfully) of a line of dialog. Much research has shown that memory for the surface form is short-lived, typically decaying to a strength of zero after 4 days (Kintsch *et al.*, 1990; Kintsch, 1998; Schmalhofer & Glavanov, 1986; Zwaan & Radvansky, 1998). Readers also develop a representation of the propositions in the text, which is a structured set of relations that code the links between predicates and arguments, called the *textbase*. The textbase is likely also embellished with propositions from general knowledge (Kintsch, 1998). The textbase is more durable than the surface form (Kintsch *et al.*, 1990). Although this representation is an abstraction from the exact textual input, it is largely a representation of the text and the concepts it mentions, as its name implies. However, readers come away with much more than a memory for the words in a story and their relations to propositions. They also come away with a memory for the situation the text describes, which is abstracted from both the exact words used and from the specific propositions asserted or implied by the text (van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). This representation is a situation model. Situation models provide a parsimonious account of a number of features of narrative comprehension: During reading, comprehenders track dimensions of the story world, including the characters, their goals, the objects with which they interact, causality, time, and space; this leads to slowing during reading when these dimensions change (Zwaan & Radvansky, 1998). Readers regularly assume information that is not stated in the text nor directly implied by specific propositions (Graesser, Singer, & Trabasso, 1994). Afterwards, they have trouble distinguishing between facts that were actually asserted by the story and facts that are consistent with the story's situation but unstated (Bransford, Barclay, & Franks, 1972). However, to make sense of such effects one needs to specify how particular features of the text are incorporated into one situation model or another one, and how successive situation models are created, updated, and possibly destroyed.

Segmentation of narrative into events

One possibility for how successive situation models are constructed is that at any given time a reader actively maintains one model that represents the current situation, and updates the model when features of the situation change (Zwaan & Radvansky, 1998). Radvansky and Zacks (2014) refer to this as the *working model*. The working model depends on recurrent neural activity, and has been proposed to be implemented in part by interactions between the prefrontal cortex and other cortical systems (Zacks *et al.*, 2007). Memory for previous events depends on synaptic changes and is associated with the hippocampus and adjacent structures in the medial temporal lobes. On this account, the distinction between *working memory* and *long-term memory* for narrative is not a matter of the delay between when one encounters material and when it is tested; instead, the critical question is whether one has updated one's working model.

How might readers update their working models? There are at least two mechanisms readers could bring to bear: *incremental* and *global* updating. In incremental updating, one component of a model is updated while the rest of the model remains intact. In global updating, a current situation model is abandoned and a new one is created from whole cloth. Incremental and global updating are not mutually exclusive; however, they are reflected to different degrees in different theories.

The event-indexing model (Magliano, Zwaan, & Graesser, 1999; Zwaan, Langston, & Graesser, 1995; Zwaan, Magliano, & Graesser, 1995; Zwaan & Radvansky, 1998) focuses on incremental updating. It proposes that situation models are organized around salient dimensions of the activity described by the text. What makes a dimension salient? This may depend on the reader's background and goals, but some dimensions are likely to be salient to most readers most of the time. Salient dimensions may include the characters and objects the story is about, temporal location, spatial location, characters' goals, and causes. When there is a shift on any salient dimension, such as when a new character enters the scene, the reader updates their working model to make their model current. This updating mechanism is incremental because only the changed information is updated, and an update on one dimension leaves the others untouched. For example, consider a scene where a child enters a kitchen and pours herself a bowl of cereal. As the child places the bowl on the counter and grabs the milk, there is a change in object contact, which gets updated in the model. However, the working model's representation of the spatial location (kitchen) and goal (to have breakfast) remain active and unaltered.

Event segmentation theory (EST) (Zacks *et al.*, 2007) focuses on global updating. It proposes a representational format similar to that proposed by the event-indexing model, with situation models that represent information about characters and objects, time, space, goals, causes, and potentially other dimensions. Event segmentation theory differs in that it proposes that the ongoing narrative is segmented into events, that the representation of the current event is maintained actively in a working model, and that at an event boundary the reader's working model is updated globally; a new working model is created based on the currently activated information and information in long-term semantic and episodic memory. The mechanism of segmentation proposed by EST is this: a reader's comprehension system continuously makes predictions about what information will be presented next in the text. These predictions are based on the current situation model (and on long-term episodic memory and knowledge). The comprehension system also monitors the quality of its predictions, comparing predicted information to what is actually presented and calculating a prediction error. When prediction error spikes, the narrative is segmented and the reader's working model is updated globally (Kurby & Zacks, 2012; Speer, Zacks, & Reynolds, 2007; Zacks, Speer, & Reynolds, 2009). Consider our example in which the child grabs milk to pour into a bowl of cereal. As the child finishes placing the bowl on the counter and turns to reach for the milk, this renders the activity a little less predictable. For example, if the text was "Jill reached for the . . .," the sentence could go on with "milk," but also could go on with "cereal," or "spoon," or "strawberries." As this example illustrates, prediction error spikes tend to occur when situational features change, and so both the event-indexing model and EST predict that updating will occur when more is changing in the situation. However, they differ in the form of the updating: the incremental updating proposed by the event indexing model affects only the information that has changed, whereas the global updating proposed by EST predicts that unchanged information is updated too. One important consequence of EST's global updating mechanism is that the information used to set up the new model has special status in working memory (Swallow, Zacks, & Abrams, 2009).

The structure-building framework (Gernsbacher, 1997) integrates both incremental and global updating. According to this theory, readers construct working models through the action of three processes: *foundation laying*, *mapping*, and *shifting*. Readers lay an initial structure for the working model using the first content encountered in the story. Onto this structure, readers map incoming information from the story. As long as the incoming story information maps on with an acceptable amount of fluency, the model grows. If mapping becomes difficult, however, such as when there is a change in the story, the reader shifts to build a brand new model. Once the shift occurs, the process starts again. The structure-building framework argues that because of the foundation-laying process, initial information at new sections – beginnings of sentences, paragraphs, episodes, etc. – has special status in the working model. It guides the mapping of new information.

In information-processing terms, the strongest dissociation between an incremental and global updating mechanism is seen in the fate of information that remains unchanged during an update. For example, suppose one were to read this passage: "Mr. Birch picked up a fishing rod, a short one with a spring in it, and started out the back door with it. The rod was rigged with a reel and a line at the end of which there was a spark plug. Mr. Birch walked out behind the house until he stood just west of the clothesline, facing the barn." The first two sentences give information about an object, the fishing rod. The third sentence changes the spatial location of the action. After this shift in location, what is the fate of information about the fishing rod? To the extent that updating is incremental, the information about this fishing rod should be unaffected because it is unchanged. However, to the extent that updating is global information about the fishing rod should be vulnerable even though it did not change. Recent studies of reading in our laboratory provide evidence that unchanged information *is* affected when readers update their situation models. However, changed information is more affected than unchanged information. This pattern of results supports the influence of both incremental and global updating on comprehension (Bailey, Kurby, Sargent, & Zacks, unpublished data; Kurby & Zacks, 2012).

Neurophysiology of situation model construction

What brain mechanisms are responsible for the construction of situation models? Some evidence is available from neuropsychological studies (Jung-Beeman, 2005); however, most of the evidence comes from neuroimaging studies, and it is on these that we will focus. One fMRI study (Friese, Rutschmann, Raabe, & Schmalhofer, 2008) adapted a behavioral paradigm developed by Schmalhofer and Glavanov (1986). In the Friese *et al.* (2008) study, participants read context sentences describing a situation and were asked to verify whether a test statement was sensible given the sentence. In one example, participants read about a passenger on a plane who was served a glass of wine when some turbulence occurred. The test statement was "wine spilled." There were four versions of the context sentences, which were written to vary the overlap between the test statement and the levels of representation of the context sentence. In the *explicit* condition, the context sentence was: "While the flight attendant served the passenger a glass of red wine turbulence caused the wine to spill." In this condition, the test statement overlapped with all three textbase representations of the sentence (the surface form, propositional, and situation). In the *paraphrase* condition, the context sentence was: "While the flight attendant served the passenger a glass of red wine turbulence caused the wine to splash." Here the test statement overlapped with propositional textbase and situation but not the surface form. In the *inference* condition, the context sentence was: "While the flight attendant served the passenger a glass of red wine turbulence occurred which was very severe." In this case, the test statement overlapped with the situation only. (Participants also verified test statements unrelated to the context sentence.) Friese *et al.* (2008) constructed a set of contrasts to separate brain activation patterns in response to each of the three levels of representation. They found that distinct brain regions increased in activity for each of these levels. Specific to situation model processing, there was an increase of left dorsomedial prefrontal cortex (dmPFC) for inference items compared to paraphrases. Regions in the right and left middle temporal lobes increased in activity for propositional comparisons. They found marginal evidence for the activation of right posterior cingulate cortex for paraphrase items compared to explicit items – surface level comparisons.

Robertson *et al.* (2000) asked which brain regions responded to the integration of sentences into a larger discourse. They had people read sets of sentences that could be integrated into a larger discourse or not, depending whether each sentence began with an indefinite ("a") or definite ("the") article. (Sentences that start with a definite article are easier to integrate into a discourse representation because definite articles signal repeated reference to a previously mentioned entity.) Compared to reading sets of indefinite-article sentences, the reading of sets of definite-article sentences was associated with an increase in activity in regions of the right superior frontal and right medial frontal cortex. (This contrast also revealed reduced activity in left inferior frontal and left anterior cingulate for definite article sentences.)

Kuperberg *et al.* (2006) investigated the neural correlates of causal inferencing during discourse comprehension. Participants read three-sentence sets that varied whether the last sentence in the set was highly causally related, intermediately related, or unrelated to the previous sentences. Participants rated the extent to which the final sentence fit. For intermediately related sentences, which require participants to draw a causal inference to understand them, there was activation of bilateral dmPFC, left lateral frontal, left inferior frontal, left parietal, and left middle temporal cortex. In a similar study, Siebörger, Ferstl, and von Cramon (2007) had participants rate the coherence of sentence pairs that varied on their strength of causal relation. Siebörger *et al.* (2007) reasoned that when participants rated the unrelated sentence pairs as somewhat coherent they were engaging in self-generated coherence-building processes. For these items, activity increased in a collection of frontal regions including the left inferior frontal, left superior frontal, left lateral orbital, and left middle frontal. Activation also was found in the parietal lobe at the angular gyrus, bilaterally, and the right intraparietal sulcus. These results converge nicely with other work on discourse processing; the dmPFC has frequently been implicated in situation model processing and maintenance (Xu *et al.*, 2005).

Indeed, the dmPFC appears to be a hub of a network that responds during reading tasks, called the extended language network (ELN) (Ferstl *et al.*, 2008). According to Ferstl *et al.* (2008), most reading experiences engage the perisylvian language areas, particularly in the left hemisphere. Outside of these areas, there is typically activation of the anterior temporal lobes, the superior temporal sulcus and inferior frontal gyrus in response to contrasts against reading single words or nonsense sentences. And, critically for the current discussion, the dmPFC and regions in the precuneus increase in activity typically when reading for coherence, sometimes revealed when readers make explicit judgments of coherence (Siebörger *et al.*, 2007). For a thorough review of the ELN see Ferstl *et al.* (2008), Ferstl (2010), and Zacks and Ferstl (2015).

Naturalistic construction of situation models

Much of the neuroimaging research to date on reading comprehension has used short artificial texts, or "textoids," that are constructed to test isolated components of comprehension (Graesser, Millis, & Zwaan, 1997). Further, most of these studies have used tasks that alter the normal reading comprehension process, such as judgments of sensibility or memory tests. Although these methodologies allow one to control surface features such as word frequency and syntax, they fail in controlling for higher-level processes, such as global coherence building and maintenance. Additionally, the use of concurrent tasks during reading may alter mechanisms engaged during reading. To what extent do the previous findings on text comprehension apply to comprehension for naturalistic materials in more naturalistic settings?

For the most part, neuroimaging studies of naturalistic discourse comprehension converge nicely with previous neuroimaging work on situation models (Ferstl, 2010). In one such study, Xu *et al.* (2005) had participants read single words, isolated sentences, and larger narratives in the scanner, one word at a time. The narratives were a selection of *Aesop's Fables*. They were coded for a number of lexical and linguistic features including word frequency, concreteness, grammatical class, and syntactic complexity. Texts were selected that matched across these sets of features. In comparison to reading single letters, all the texts (single words, single sentences, and narratives) activated perisylvian language areas. Additionally, in comparison to sentences, narratives activated regions bilaterally in the precuneus, the dmPFC, and the ventral medial prefrontal cortex (vmPFC). There was also increased activity in left middle temporal gyrus, posterior superior temporal sulcus, and lateral premotor cortex.

A critical feature of situation models is that they maintain and integrate global information about the described events. As events unfold, there are changing demands on the comprehension systems that need to be met for comprehension to be successful. Might the dmPFC be critical to such maintenance? Yarkoni, Speer, and Zacks (2008) investigated the brain systems involved in building and maintaining a working model, and the relation between regional activity and subsequent memory for the stories. They also tested for regions that showed changed dynamics as the story unfolded. In their study, participants read blocks of naturalistic narratives that were either coherent stories or scrambled stories – blocks of sentences with their order randomized. The stories were edited excerpts from a book called *One Boy's Day*, which is an observational record of a young boy's activities throughout an entire day (Barker & Wright, 1951). The stories were presented one word at a time and participants were instructed simply to read the texts for a later memory test. After each text, participants took a sentence recognition test and a four-alternative multiple-choice comprehension test. In their analyses, the authors tested for regions that changed their activation depending on story type (coherent vs. scrambled) and for regions that increased their activation over the course of each story. A number of regions showed a larger fMRI response for coherent stories than for scrambled stories, including the bilateral middle temporal gyrus, bilateral inferior frontal gyrus, left dorsal premotor cortex, and bilateral dmPFC. Further, most of these regions also increased in activity for the scrambled condition compared to baseline, suggesting that they play a role in both sentence-level and discourse-level processing. The exception was the dmPFC, which increased only during the coherent story conditions, suggesting that the dmPFC specializes in discourse-level processing only. In their analysis of temporal dynamics, they observed a set of regions in posterior parietal cortex that increased in activity at the beginning of text blocks but then decreased thereafter. These regions may be important for the initial construction of situation models, consistent with the structure-building framework. They also found a collection of frontal and temporal regions, such as right premotor cortex and anterior temporal lobe, that increased in activity as the story unfolded. This suggests these regions are important for the maintenance of situation models (see Plate 4.1 in color plate section). Additionally, the activity in a number of regions during the story condition, including the dmPFC, was positively correlated with recognition memory, and activity in the right premotor cortex, as well as left middle temporal gyrus and right cerebellum, was positively correlated with better comprehension test performance.

Further work, using naturalistic materials, has revealed the brain regions associated with the segmentation of narratives into events, perhaps similar to the so-called shifting mechanism of the structure-building framework. Speer, Zacks, and Reynolds (2007) had participants read extended excerpts (around 180 clauses long) from *One Boy's Day* (Barker & Wright, 1951), presented one word at a time, during fMRI scanning. Afterwards, participants segmented the narratives into large (coarse) and small (fine) events. Large regions in temporal-parietal cortex – bilateral precuneus, anterior temporal, and posterior superior temporal gyrus – right posterior cingulate, and right middle frontal gyrus increased in activity in a window around event boundaries. (Most regions showed larger effects for coarse than fine boundaries.) Whitney *et al.* (2009) investigated the neural correlates of processing narrative shifts. Participants passively listened to a 3581-word German novella while their brain activity was recorded with fMRI. The narrative was coded for shifts in time, space, action, and character. Compared to the effect of encountering a sentence boundary, narrative shifts (collapsed across type) elicited activity in the right precuneus, the right posterior cingulate, and the left middle cingulate cortex. Ezzyat and Davachi (2011) similarly investigated the brain response to narrative shifts, in this case temporal shifts, but also asked whether separate mechanisms contributed to the maintenance of event information vs. updating at event boundaries. Participants read extended narratives that occasionally shifted time with the phrase, "A while later" or maintained continuity with the phrase "A moment later." Compared to the sentences that maintained continuity, for the event boundaries there was an increase in activity in a large region in the right precuneus, the right ventrolateral PFC, the right dmPFC, and left superior temporal gyrus. Similarly to Yarkoni *et al.* (2008), Ezzyat and Davachi (2011) tested for regions that increased in activity over the course of each event. Those regions were bilateral ventromedial PFC, left middle temporal gyrus, and right parahippocampal cortex (see Plate 4.2 in color plate section). Further, they tested whether activity in these regions associated with event boundaries and event maintenance correlated with memory for the events. After reading each story, participants engaged a cued-recall priming paradigm to measure within-event binding. Ezzyat and Davachi (2011) found that regions which increased in activity across an event correlated with within-event binding (see Plate 4.3 in color plate section).

The above studies reveal that there is a consistent collection of brain regions that respond to the demands of situation model processing, from shifting, to construction, to maintenance (see also Ferstl (2010) for a review). A very consistent result is that the dmPFC is selectively activated under conditions in which readers construct situation models. In addition, the precuneus usually increases in activity when readers need to make inferences to establish coherence. Finally, regions including the lateral frontal cortex and regions in the temporal lobes may be important for situation model maintenance. While our review so far has discussed the processes that serve situation model processing, we are left with an important question: What is the form of representation of situation models?

Sensorimotor simulations: the form of representation of situation models

Over the last decade, embodied cognition theories have gained support from both behavioral and neuroimaging research (Barsalou, 2008). These theories argue that the brain systems important for perception and action play a critical role in the representation of knowledge (Barsalou, 2008; Gallese & Lakoff, 2005; Glenberg, 1997; Glenberg & Gallese, 2012; Zwaan, 2004). This approach has been applied to the construction of situation models, proposing that readers generate perceptual simulations of the events described in language (Zwaan, 2004). For example, in theory, when reading a sentence about a pitcher throwing a ball, the sensorimotor system important for grasping and throwing performs the neural computations needed and emulates the action, rather than engaging the body to externally conduct it (Fischer & Zwaan, 2008; Glenberg & Gallese, 2012). When reading about a visual scene, the visual system engages to mentally construct the scene from knowledge. The same logic holds for the other senses. It is likely that event models, and situation models specifically, are composed in part by sensorimotor simulations (Zwaan, 2004).

Much neuroimaging work supports the possibility that readers activate sensorimotor systems during language tasks. The majority of the studies used very short texts, sometimes single words or phrases, and at times included explicit judgment tasks. Hauk, Johnsrude, and Pulvermüller (2004) presented participants with action verbs, such as "pick," "lick," and "kick" while the participants laid in the scanner. Results showed topographically organized activity in the sensorimotor and motor cortex corresponding to the effector relevant to the action. Such results have been replicated a number of times, using slightly different tasks and

dependent measures, and using action phrases instead of single words (Aziz-Zadeh *et al.*, 2006; Desai *et al.*, 2010; Tettamanti *et al.*, 2005; Willems, Hagoort, & Casasanto, 2010). For example, Willems and colleagues (2010) found that when making lexical decisions for manual verbs, right-handers activated left motor cortex more than right motor cortex, and left-handers activated right motor cortex more than left. This shows that simulations are limb-specific.

Simulation results also have been found for visual and auditory processing. Judgments about object color from verbal stimuli activate left fusiform gyrus (Simmons *et al.*, 2007), a higher-level visual area, and recall for pictures activates large areas of occipital cortex (Wheeler, Petersen, & Buckner, 2000). Making judgments about the sounds of objects (Kellenbach, Brett, & Patterson, 2001) and recall for sounds (Wheeler *et al.*, 2000) activate auditory regions such as the posterior superior temporal gyrus and middle temporal gyrus. Simulation effects have emerged also in the study of speech comprehension. Yao, Belin, and Scheepers (2011) found that the silent reading of speech activates speech-selective areas.

But how well do these results generalize to naturalistic reading? Do readers activate sensorimotor systems as a normal part of comprehending complete sentences or discourse, or do these effects require artificial stimuli and tasks? The inclusion of judgment tasks such as identifying colors or sounds is certainly not typical of most reading situations and may increase the probability that one would generate a simulation. A similar concern exists for work on motor simulation in language comprehension where participants are often asked to turn dials or push and pull levers (Fischer & Zwaan, 2008; Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006).

In a notable study, Deen and McCarthy (2010) tested whether readers simulate the biological motion of characters in a story. Participants read short stories, averaging 70 words each, which described biological motion of characters, such as characters walking or moving objects, or non-biological motion. Participants read the stories for comprehension without an explicit judgment task. A biological motion localizer was used to identify biological-motion-sensitive brain regions, typically the posterior superior temporal sulcus (pSTS) (Allison, Puce, & McCarthy, 2000). Deen and McCarthy (2010) found that participants activated pSTS more for the biological motion texts than the non-biological motion ones, and that region overlapped with the regions activated by the localizer. A study by Wallentin *et al.* (2011) found that left posterior middle temporal gyrus, a region known to increase in activity for the reading of motion verbs in isolation (Kable, Lease-Spellmeyer, & Chatterjee, 2002), also increased in activity for motion verbs embedded in larger discourse.

These studies show that readers activate sensorimotor regions during comprehension, but what role do they play in situation model processing? In one possibility, these regions are engaged when the model needs to be updated. Speer *et al.* (2009) investigated the brain regions engaged when there are changes in situational dimensions in the story. Recall that according to the event-indexing model, readers track six situational dimensions – time, space, characters, goals, objects, and causes – and update their situation models when they change. Speer *et al.* (2009) conducted a theoretically driven analysis of the texts to code for points in the story where there were situational shifts. In the study, participants read extended discourses (approximately 180 clauses long), one word at a time, in the scanner. Critically, similar to Deen and McCarthy (2010), participants' only task was to read for comprehension. They did not engage in any explicit judgment tasks. They found that different brain regions responded to the different types of situational change. In some cases the areas activated for changes on a particular dimension were associated with processing that dimension in perception and action. For example, changes in character goals selectively activated a portion of prefrontal cortex which is known to play a role in the comprehension of goal directed behavior (Wood & Grafman, 2003). Changes in object interaction selectively activated left premotor cortex. The bilateral parahippocampal gyrus, important for the perceptual processing of spatial location change (Burgess, Maguire, & O'Keefe, 2002), increased in activity for spatial shifts in the story. (This region responded to other types of situation change as well.) These results suggest that when updating situation models, brain systems are engaged that are important to the type of information being updated.

Kurby and Zacks (2013) investigated whether readers activate modality-specific representations during naturalistic discourse comprehension. The study was a reanalysis of data from Speer *et al.* (2009) and Yarkoni *et al.* (2008). We asked whether readers activate visual, auditory, or somatomotor regions when encountering visual, auditory, or motor information in the story. Through norming and coding procedures, clauses were identified that elicited strong mental imagery in either the visual, auditory, or motor modality. The reading of auditory imagery clauses, such as descriptions of sounds or lines of dialog, was associated with activation in a number of regions in secondary auditory cortex, including middle temporal gyrus, and posterior superior temporal gyrus. These clauses also activated perisylvian language regions, such as the inferior frontal gyrus. The reading of motor clauses, which were descriptions of actions, activated left premotor and left secondary sensorimotor cortex. (There were no effects of reading visual imagery clauses.) These

results suggest that readers activate sensorimotor simulations during the comprehension of extended discourse with the simple goal of reading to understand (see Plate 4.4 in color plate section).

Although readers generate situation models and can also generate sensorimotor simulations, it is currently unknown whether simulations are necessary for situation model construction. Strong claims have been made that simulations are necessary (Glenberg & Gallese, 2012); however, no data to date clearly support that claim. Indeed, some studies of conceptual knowledge have revealed that people do not always activate sensorimotor representations when reading about verbs (Bedny *et al.*, 2008) or making perceptual judgments about objects (Louwerse, 2011; Louwerse & Jeuniaux, 2010). We recently asked a readily testable question: Do simulations depend on situation models? In Kurby and Zacks (2013), in Study 2, we reasoned that if simulation results from forming a situation model, then disrupting the ability to form a situation model should disrupt simulation. To test this hypothesis, we reanalyzed data from Yarkoni *et al.* (2008), using the same norming and coding procedures described above to identify high-imagery clauses. Recall that in Yarkoni *et al.* (2008), participants read discourse that was either a coherent story or scrambled stories – sets of unrelated sentences. Using the regions of interest (ROIs) from Study 1 of Kurby and Zacks (2013), we replicated the imagery effects in the story condition, but none of the imagery effects replicated in the scrambled condition. Most of the imagery effects were significantly larger in the story condition than scrambled condition. These data support the possibility that sensorimotor simulations are engaged during situation model processing. And, further, simulations are not generated when the reader is unable to form a global situation model (see Figure 4.1).

However, these data do not establish that simulation is *necessary* for situation model construction. It may be that simulations provide embellishment or elaboration on situation models rather than forming the foundation of the mental model (Mahon & Caramazza, 2008). They may be downstream from situation models. There are a number of directions research needs to go to further investigate whether simulations are necessary. It will be important to test whether situation models can be constructed in the absence of simulations, as has been argued elsewhere (Zwaan, 2004). Additionally, it will be important to characterize the association between activity in situation model related regions and activity in sensorimotor regions. Are their activity correlated? Or de-phased in time? Of interest would be whether simulations occur prior to situation model operations, or the reverse, or whether they co-occur.

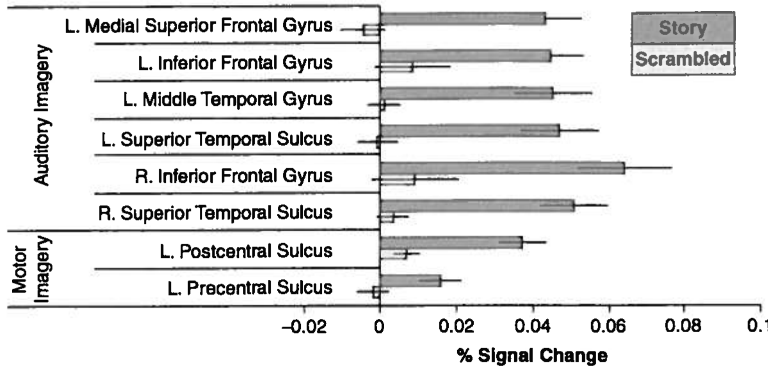

Figure 4.1 Regions that showed modality-specific imagery effects in Kurby and Zacks (2013), Study 1, increased in activity only during the reading of coherent stories (Study 2). Reproduced with permission.

Conclusion

In this chapter, we have discussed situation models in language comprehension. During comprehension, readers construct a working model that represents the current state of affairs. The working model is kept current through a combination of incremental and global updating. A diverse set of brain regions play an important role in each of these processes. Regions in posterior cortex, such as the precuneus and parietal cortex, may subserve the establishment of a new model during global updating (Ferstl, 2010; Yarkoni *et al.*, 2008). Frontal regions, with dmPFC featuring prominent, may play a large part in maintaining the working model (Ferstl *et al.*, 2008; Friese *et al.*, 2008; Xu *et al.*, 2005). Populating the model with situational features appears to engage content-specific neural systems (Speer *et al.*, 2009). Segmenting the situation to initiate global updating of the working model engages a network of temporal-parietal-occipital regions, as well as prefrontal (Speer *et al.*, 2007; Zacks *et al.*, 2001). Situational models appear to function as sensorimotor simulations of the described events, at least in part, and therefore draw on the same neural systems as are used for perception and action. Although a majority of the neuroimaging research on situation models uses short texts, and sometimes unnatural tasks, a large portion of these findings have come from studies using more naturalistic conditions. We look forward to further tests of situation model processing in discourse comprehension in reading conditions similar to everyday experiences.

References

Allison, T., Puce, A., & McCarthy, G. (2000). Social perception from visual cues: role of the STS region. *Trends in Cognitive Sciences, 4,* 267–278.
Aziz-Zadeh, L., Wilson, S., Rizzolatti, G., & Iacoboni, M. (2006). Congruent embodied representations for visually presented actions and linguistic phrases describing actions. *Current Biology, 16,* 1818–1823.
Barker, R. G., & Wright, H. S. (1951). *One Boy's Day: A Specimen Record of Behavior.* Oxford: Harper.
Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59,* 617–645.
Bedny, M., Caramazza, A., Grossman, E., Pascual-Leone, A., & Saxe, R. (2008). Concepts are more than percepts: the case of action verbs. *Journal of Neuroscience, 28,* 11347–11353.
Bransford, J. D., Barclay, J. R., & Franks, J. J. (1972). Sentence memory: a constructive versus interpretive approach. *Cognitive Psychology, 3*(2), 193–209. doi: http://dx.doi.org/10.1016/0010-0285(72)90003-5
Burgess, N., Maguire, E. A., & O'Keefe, J. (2002). The human hippocampus and spatial and episodic memory. *Neuron, 35*(4). doi:10.1016/S0896-6273(02)00830-9
Deen, B., & McCarthy, G. (2010). Reading about the actions of others: biological motion imagery and action congruency influence brain activity. *Neuropsychologia, 48,* 1607–1615.
Desai, R. H., Binder, J. R., Conant, L. L., & Seidenberg, M. S. (2010). Activation of sensory–motor areas in sentence comprehension. *Cerebral Cortex, 20,* 468–478.
Ezzyat, Y., & Davachi, L. (2011). What constitutes an episode in episodic memory? *Psychological Science, 22*(2), 243–252. doi:http://dx.doi.org/10.1177/0956797610393742
Ferstl, E. C. (2010). Neuroimaging of text comprehension: where are we now? *Italian Journal of Linguistics, 22*(1), 61–88.
Ferstl, E. C., Neumann, J., Bogler, C., & von Cramon, D. Y. (2008). The extended language network: a meta-analysis of neuroimaging studies on text comprehension. *Human Brain Mapping, 29,* 581–593.
Fischer, M. H., & Zwaan, R. A. (2008). Embodied language: a review of the role of motor system in language comprehension. *Quarterly Journal of Experimental Psychology, 61*(6), 825–850. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1080/17470210701623605
Friese, U., Rutschmann, R., Raabe, M., & Schmalhofer, F. (2008). Neural indicators of inference processes in text comprehension: an event-related functional magnetic resonance imaging study. *Journal of Cognitive Neuroscience, 20*(11), 2110–2124. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1162/jocn.2008.20141
Gallese, V., & Lakoff, G. (2005). The brain's concepts: the role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology, 22*(3–4), 455–479. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1080/02643290442000310
Gernsbacher, M. A. (1997). Two decades of structure building. *Discourse Processes, 23,* 265–304.
Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences, 20,* 1–55.

Glenberg, A. M., & Gallese, V. (2012). Action-based language: a theory of language acquisition, comprehension, and production. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior, 48*(7), 905–922. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1016/j.cortex.2011.04.010

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin and Review, 9*, 558–565.

Graesser, A. C., Golding, J. M., & Long, D. L. (1991). Narrative representation and comprehension. In R. Barr, M. L. Kamil, P. Mosenthal, & P. D. Pearson (eds.), *Handbook of Reading Research*, pp. 171–205. London: Longman.

Graesser, A. C., Millis, K. K., & Zwaan, R. A. (1997). Discourse comprehension. *Annual Review of Psychology, 48*, 163–189.

Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review, 101*(3), 371–395. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1037/0033-295X.101.3.371

Hauk, O., Johnsrude, I., & Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron, 41*, 301–307.

Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language. *Trends in Cognitive Science, 9*, 512–518.

Kable, J. W., Lease-Spellmeyer, J., & Chatterjee, A. (2002). Neural substrates of action event knowledge. *Journal of Cognitive Neuroscience, 14*, 795–805.

Kellenbach, M. L., Brett, M., & Patterson, K. (2001). Large, colorful, or noisy? Attribute- and modality-specific activations during retrieval of perceptual attribute knowledge. *Cognitive, Affective and Behavioral Neuroscience, 1*, 207–221.

Kintsch, W. (1998). *Comprehension: A Paradigm for Cognition*. New York: Cambridge University Press.

Kintsch, W., Welsch, D., Schmalhofer, F., & Zimny, S. (1990). Sentence memory: a theoretical analysis. *Journal of Memory and Language, 29*(2), 133–159. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1016/0749-596X(90)90069-C

Kuperberg, G. R., Lakshmanan, B. M., Caplan, D. N., & Holcomb, P. J. (2006). Making sense of discourse: an fMRI study of causal inferencing across sentences. *NeuroImage, 33*(1). doi:10.1016/j.neuroimage.2006.06.001

Kurby, C. A., & Zacks, J. M. (2012). Starting from scratch and building brick by brick in comprehension. *Memory and Cognition, 40*, 812–826.

Kurby, C. A., & Zacks, J. M. (2013). The activation of modality-specific representations during discourse processing. *Brain and Language, 126*, 338–349.

Louwerse, M. M. (2011). Symbol interdependency in symbolic and embodied cognition. *Topics in Cognitive Science, 3*(2), 273–302. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1111/j.1756-8765.2010.01106.x

Louwerse, M. M., & Jeuniaux, P. (2010). The linguistic and embodied nature of conceptual processing. *Cognition, 114*, 96–104.

Magliano, J. P., Zwaan, R. A., & Graesser, A. C. (1999). *The role of situational continuity in narrative understanding*. In H. van Oostendorp & S. R. Goldman (eds.), *The Construction of Mental Representations during Reading*, pp. 219–245. Mahwah, NJ: Lawrence Erlbaum Associates.

Mahon, B. Z., & Caramazza, A. (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology – Paris, 102*, 59–70.

Radvansky, G. A., & Zacks, J. M. (2014). *Event Cognition*. New York: Oxford University Press.

Rayner, K., Raney, G. E., & Pollatsek, A. (1995). Eye movements and discourse processing. In R. F. Lorch & E. J. O'Brien (eds.), *Sources of Coherence in Reading*, pp. 9–35. Hillsdale, NJ: Lawrence Erlbaum Associates.

Robertson, D. A., Gernsbacher, M. A., Guidotti, S. J., Robertson, R. R. W., 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. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1111/1467-9280.00251

Schmalhofer, F., & Glavanov, D. (1986). Three components of understanding a programmer's manual: verbatim, propositional, and situational representations. *Journal of Memory and Language, 25*(3), 279–294. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1016/0749-596X(86)90002-1

Siebörger, F. T., Ferstl, E. C., & von Cramon, D. Y. (2007). Making sense of nonsense: an fMRI study of task induced inference processes during discourse comprehension. *Brain Research, 1166*, 77–91. doi:10.1016/j.brainres.2007.05.079

Simmons, W. K., Ramjee, V., Beauchamp, M. S., McRae, K., Martin, A., & Barsalou, L. W. (2007). A common neural substrate for perceiving and knowing about color. *Neuropsychologia, 45*, 2802–2810.

Speer, N. K., Reynolds, J. R., Swallow, K. M., & Zacks, J. M. (2009). Reading stories activates neural representations of visual and motor experiences. *Psychological Science, 20*, 989–999.

Speer, N. K., Zacks, J. M., & Reynolds, J. R. (2007). Human brain activity time-locked to narrative event boundaries. *Psychological Science, 18*, 449–455.

Swallow, K. M., Zacks, J. M., & Abrams, R. A. (2009). Event boundaries in perception affect memory encoding and updating. *Journal of Experimental Psychology: General, 138*, 236–257.

Tettamanti, M., Buccino, G., Saccuman, M. C., Gallese, V., Danna, M., Scifo, P., . . ., Perani, D. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience, 17*, 273–281.

van Dijk, T. A., & Kintsch, W. (1983). *Strategies in Discourse Comprehension*. New York: Academic Press.

Wallentin, M., Nielsen, A. H., Vuust, P., Dohn, A., Roepstorff, A., & Lund, T. E. (2011). BOLD response to motion verbs in left posterior middle temporal gyrus during story comprehension. *Brain and Language, 119*(3), 221–225. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1016/j.bandl.2011.04.006

Wheeler, M. E., Petersen, S. E., & Buckner, R. L. (2000). Memory's echo: vivid remembering reactivates sensory-specific cortex. *Proceedings of the National Academy of Sciences USA, 97*, 11 125–11 129.

Whitney, C., Huber, W., Klann, J., Weis, S., Krach, S., & Kircher, T. (2009). Neural correlates of narrative shifts during auditory story comprehension. *NeuroImage, 47*(1). doi:10.1016/j.neuroimage.2009.04.037

Willems, R. M., Hagoort, P., & Casasanto, D. (2010). Body-specific representations of action verbs: neural evidence from right- and left-handers. *Psychological Science, 21*, 67–74.

Wood, J. N., & Grafman, J. (2003). Human prefrontal cortex: processing and representational perspectives. *Nature Reviews Neuroscience, 4*(2), 139–147. doi: http://dx.doi.org.ezproxy.gvsu.edu/10.1038/nrn1033

Xu, J., Kemeny, S., Park, G., Frattali, C., & Braun, A. (2005). Language in context: emergent features of word, sentence, and narrative comprehension. *NeuroImage, 25*(3). doi:10.1016/j.neuroimage.2004.12.013

Yao, B., Belin, P., & Scheepers, C. (2011). Silent reading of direct versus indirect speech activates voice-selective areas in the auditory cortex. *Journal of Cognitive Neuroscience, 23,* 3146–3152. doi:http://dx.doi.org.ezproxy.gvsu.edu/10.1162/jocn_a_00022

Yarkoni, T., Speer, N. K., & Zacks, J. M. (2008). Neural substrates of narrative comprehension and memory. *NeuroImage, 41,* 1408–1425.

Zacks, J. M., Braver, T. S., Sheridan, M. A., Donaldson, D. I., Snyder, A. Z., Ollinger, J. M., . . ., Raichle, M. E. (2001). Human brain activity time-locked to perceptual event boundaries. *Nature Neuroscience, 4,* 651–655.

Zacks, J. M., & Ferstl, E. C. (2015). Discourse comprehension. In G. Hickok & S. L. Small (eds.), *Neurobiology of Language.* Amsterdam: Elsevier Science Publishers.

Zacks, J. M., Speer, N. K., & Reynolds, J. R. (2009). Segmentation in reading and film comprehension. *Journal of Experimental Psychology: General, 138,* 307–327.

Zacks, J. M., Speer, N. K., Swallow, K. M., Braver, T. S., & Reynolds, J. R. (2007). Event perception: a mind-brain perspective. *Psychological Bulletin, 133,* 273–293.

Zwaan, R. A. (2004). The immersed experiencer: toward an embodied theory of language comprehension. In B. H. Ross (ed.), *The Psychology of Learning and Motivation,* pp. 35–62. Amsterdam: Elsevier Science Publishers.

Zwaan, R. A., Langston, M. C., & Graesser, A. C. (1995). The construction of situation models in narrative comprehension: an event-indexing model. *Psychological Science, 6,* 292–297.

Zwaan, R. A., Magliano, J. P., & Graesser, A. C. (1995). Dimensions of situation model construction in narrative comprehension. *Journal of Experimental Psychology: Learning, 21*(2), 386–397.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123,* 162–185.

Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: motor resonance in language comprehension. *Journal of Experimental Psychology: General, 135,* 1–11.

5 Language comprehension in rich non-linguistic contexts: combining eye-tracking and event-related brain potentials

Pia Knoeferle

Abstract The present chapter reviews the literature on visually situated language comprehension against the background that most theories of real-time sentence comprehension have ignored rich non-linguistic contexts. However, listeners' eye movements to objects during spoken language comprehension, as well as their event-related brain potentials (ERPs), have revealed that non-linguistic cues play an important role for real-time comprehension. In fact, referential processes are rapid and central in visually situated spoken language comprehension and even abstract words are rapidly grounded in objects through semantic associations. Similar ERP responses for non-linguistic and linguistic effects on comprehension suggest these two information sources are on a par in informing language comprehension. ERPs further revealed that non-linguistic cues affect lexical-semantic as well as compositional processes, thus further cementing the role of rich non-linguistic context in language comprehension. However, there is also considerable ambiguity in the linking between comprehension processes and each of these two measures (eye movements and ERPs). Combining eye-tracking and event-related brain potentials would improve the interpretation of individual measures and thus insights into visually situated language comprehension.

Introduction

Much of our everyday language use occurs in contextually rich settings. This is true, for instance, when we select a tram ticket to go to work and follow the instructions of a vending machine; when we read the paper; or when we buy a croissant at the corner bakery. At the vending machine, for instance, we can use verbal labels such as "day-ticket" together with depictions of zones on the city map to understand which kind of ticket we are buying and where it is valid. In the bakery, we can gesture and point to a pastry if we don't know its name, and if we see the baker select a pastry