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CHAPTER 19

Language in the Brain, Body, and World

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1. Introduction

Language is a uniquely human tool. It helps us situate ourselves in the world around us by directing our attention to people, objects, events, and possibilities for action. Language also situates us in worlds separate from our immediate environment. Through descriptions of real or imagined events, it serves to draw our attention to people, objects, events, and possibilities for action that are not present in the here and now. This situating of oneself in events outside of the here and now takes place through a process of mental simulation.

Mental simulation can be considered a vicarious experiencing of the events being described. Language is a sequence of stimuli that orchestrate the retrieval of experiential traces of people, places, objects, events, and actions. This retrieval occurs in part via a rapid, direct, and passive memory process similar to the resonance process described by Hintzman (1986). The experiential traces reflect the comprehenders' past experience with particular objects, actions, and events, as well as their previous experience with language. For example, understanding a sentence about removing an apple pie from the oven would involve the retrieval of traces of motor experience (lifting the pie and feeling its weight) and perceptual experience (seeing and smelling the pie, feeling the heat coming out of the oven). The relevant memory retrieval occurs by probing the same sensorimotor processing mechanisms that would be involved if one were actually lifting, seeing, and smelling the pie (Barsalou, 1999). In a very literal sense, the comprehension of a sentence about removing the pie from the oven relies on much the same machinery that would be involved in actually carrying out the action. Understanding the sentence also involves the resonance of experiential traces of having heard, read, spoken, and written the words in the sentence.

A number of recent studies have pointed to the conclusion that the ability to mentally simulate actions (and their consequences) is crucial to our ability to plan and execute actions, and to understand the actions of others (e.g., Flanagan & Johansson, 2003; Wolpert, Doya, & Kawato, 2003). These data

P1: SQE
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form the basis of our claims about the role of mental simulation in language comprehension. Just as we understand the actions of others by internally simulating their actions, we can understand the actions of people described in language through an internal simulation of their actions (e.g., Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006). Thus, language comprehension is grounded in the same knowledge and processes that are used to support comprehension and conceptualization in many other domains (Barsalou, 1999, 2005).

The ability to experience situations vicariously is adaptive. It allows us to learn from (and empathize with) others' past experiences and to coordinate future actions. This provides the basis for anticipating future states within ourselves (or others) and in the environment. We call the process through which this anticipation arises "presonance." Presonance captures the idea that the quick-acting and passive memory retrieval posited in theories such as Hintzman's (1986) does more than simply bring forth past experiences; it also brings forth experiential memory traces that facilitate the processing of likely changes to the self or the environment. The ability to anticipate such changes to the self or the environment is crucial to the ability to plan and take action in the world (for a discussion of the role of trajectories of events in memory and memory retrieval, see Glenberg, 1997). For example, when we see a barking dog charge toward us, previous experience with similar situations tells us that the dog will continue its approach. Thus, we can prepare for this future state (approaching dog) by taking action to protect ourselves. It is important to stress that presonance should be viewed as an automatic and fast process and not as deliberative prediction.

In the context of language processing, presonance operates on many levels. Anticipating the next elements in the linguistic input – be they phonemes, words, or syntactic constructions – serves to facilitate the processing of those elements. Anticipating subsequent changes in the events being described (on a basic level, what is coming next in the story) can facilitate language comprehension (e.g., Hess, Foss, & Carroll, 1995). More broadly, knowledge about particular genres of language use allows comprehenders to anticipate the content and structure of a text, and thus tailor their reading strategies in appropriate ways (e.g., Zwaan, 1994). This anticipation is guided both by one's experience with real actions and events in the world and by one's previous experiences with language.

The claim that language processing involves the rapid use of information that points toward likely next states in the linguistic input is consistent with constraint-satisfaction views of language processing (e.g., Jurafsky, 1996; MacDonald, Pearlmutter, & Seidenberg, 1994; McRae, Spivey-Knowlton, & Tanenhaus, 1998). On this view, sentence processing proceeds by activating many possible interpretations for the sentence. These interpretations compete for activation on the basis of probabilistic information from the comprehender's experience with language. The likelihood of a particular word being used in a particular syntactic function (MacDonald et al., 1994), the likelihood of a particular syntactic structure being used (Jurafsky, 1996), the preceding context (e.g., Spivey & Tanenhaus, 1998; van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005), and other such factors are simultaneously considered as the language-processing system works to develop the most likely interpretation of the sentence. When the language refers to elements of the here and now (rather than a displaced situation), additional factors (e.g., the affordances of the objects present in the environment; Chambers, Tanenhaus, & Magnuson, 2004) also exert an influence on on-line sentence comprehension (see Spivey & Richardson, this volume). There is now considerable evidence that these sources of information are used as soon as they are available to the language-comprehension system.

Closer to our notion of mental simulation, presonance may be based on a covert use of the language-production system (Pickering & Garrod, 2004; Townsend &

P1: SQE
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Bever, 2001). On the most basic level, there is evidence to suggest that our perception of speech sounds involves the activation (resonance) of the motor programs that would be used to produce those sounds ourselves (e.g., Porter & Lubker, 1980; for a brief review and discussion, see Fowler, 1996). The use of one's language-production system while processing language also takes place on higher levels of analysis. The general idea behind this premise is that comprehenders would continuously but subconsciously ask the question, What would I say or write here if I were the speaker or writer (for a discussion, see van Berkum et al., 2005)? This mimicry approach might be an effective mechanism of lexical and syntactic anticipation depending on the degree of common ground and common experience between the producer and the recipient of the message.

Language-based presonance is a largely automatic and effortless process in which the retrieval of experiential traces is triggered by the perception of linguistic structures. Activation of these traces allows the comprehender to vicariously experience the described situation. The depth of the vicarious experience is subject to the effectiveness of presonance, which is subject to a number of factors. As just noted, one major factor is the comprehender's own experience. Presonance is presumably greatest when the comprehender's experiential traces closely match those of the described situation. For example, a sentence about shifting a car from second gear into third gear will yield a more specific mental simulation in a person experienced in driving a stick-shift car than in a person who has only driven an automatic-shift car. Specifically, one might predict that the former would show activation in the motor area for the right leg, releasing the leg from the gas pedal, followed by activation of the left leg area, as this is used to push down the clutch right before the shift is made by a right-hand power grip of the shift stick and by subsequently moving the hand forward, away from the body. The expert might furthermore activate auditory and vestibular traces of that typically accompany a stick shift. Instead of this sequence of sensorimotor activations, the automatic shift driver might only activate an auditory representation of the sound associated with a stick shift.

Another major factor in the depth of one's vicarious experience is the comprehender's language comprehension skill. On the view outlined here, language comprehension skill reflects one's sensitivity to linguistic constructs, as reflected in the strength of the links between linguistic constructions – experiential traces themselves – and nonlinguistic experiential traces (Goldberg, 1995; Zwaan, 2004; Zwaan & Madden, 2004). Even if a comprehender has relevant experiential traces, if the reader fails to bring these to bear, the ensuing mental simulation will not be coherent. For example, in a second-language learner of English who has experience with shift sticks, the relevant experiential traces will not be activated if he or she does not know the meaning of *shifting gear* (i.e., has no links between *shifting gear* and the relevant experiential traces).

The notion that language processing involves perceptual and motor simulations of the described situation cannot be derived from traditional theories of comprehension. These theories conceptualize comprehension as the construction of a mental representation of the described situation, a situation model (van Dijk & Kintsch, 1983). Various studies have demonstrated that comprehenders are sensitive to aspects of the referential situation, as evidenced by reading times and the activation and deactivation of concepts (for reviews, see Zwaan & Radvansky, 1998; Zwaan & Rapp, 2006). One limitation of this earlier work is that it makes the (often-tacit) assumption that comprehension involves the activation and integration of abstract mental representations. This assumption derives from a basic tenet of the cognitive revolution; namely, that cognition can be studied as a system of abstract rules and representations, separated from the brain and the world. The idea that abstract rules and representations can form the basis of cognition has been called into question on the basis of what has been called

P1: SQE
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the "symbol-grounding problem." Because abstract, arbitrary symbols and rules are not properly grounded in the world, they cannot form the basis of meaning (linguistic or otherwise; for discussion, see Glenberg, 1997; Harnad, 1990; Searle, 1980).

Contrary to this mind-as-computer view of cognition, the mental simulation view that we discuss in this chapter is based on the view that cognition is grounded in the systems of perception and action planning in one's own body (see also Spivey & Richardson, this volume). As a consequence, it should be possible to observe that the performance of cognitive tasks (e.g., comprehending language) involves the recruitment of one's systems of perception and action planning (as evidenced by priming and/or interference that arises between language processing on the one hand, and the performance of perceptual or motor tasks on the other hand). This prediction is now supported by a number of empirical observations involving psycholinguistic tasks. We review this literature, moving from the word level to the discourse level by means of the sentence level.

2. Experiential Traces at the Word Level

Central to the mental simulation view of language comprehension is the claim that individual words (linguistic constructs) are linked to sensorimotor memory traces that form the basis of the mental simulation. For example, when one processes the word *table*, the linguistic form resonates with perceptual traces (e.g., the shape, size, color, and other features of tables one has seen) and motor traces (e.g., actions that one has taken involving tables in the past) from one's experiences with tables. In the absence of a sharply defining context, the specific memory traces that contribute to the retrieval process will be varied and may vary across time (Barsalou, 2005). Thus, when one is talking about tables in general, there is a wide range of experiential traces that are relevant, and these will affect the retrieval process. When one is talking about a specific table (e.g., your coffee table), the range of relevant experiential traces will be much smaller.

The link between word forms and sensorimotor memory traces reflects a process of grounding language in the surrounding environment that begins in the earliest stages of language acquisition. Much of the language that very young children hear is about the people, objects, and events that surround them (e.g., Tomasello, 2003). Caregivers use gestures and other paralinguistic devices to direct children's attention toward elements of the environment that are being discussed in an effort to ground new linguistic terms in the external world (Masur, 1997). Although the linking of linguistic forms to experiential memory traces is only a part of the important work that goes into language acquisition, it provides the basis for the child's growing ability to use language to describe the world around them and (later) worlds separate from the here and now.

2.1. Perceptual Traces

There is a great deal of evidence that reading or listening to isolated words activates perceptual representations. One experiment examined whether perceptual information, specifically the shape of objects, is activated during semantic processing (Zwaan & Yaxley, 2004). Subjects judged whether a target word was related to a prime word. Prime-target pairs that were not associated, but whose referents had similar shapes (e.g., *ladder-railroad*), yielded longer "no" responses than unassociated prime-target pairs, suggesting that shape information had been activated. A visual-field manipulation showed that, in right-handed subjects, this effect was localized in the left hemisphere. This finding is consistent with behavioral, brain imaging, and lesion data, which suggest that object shape at the category level is represented in the left hemisphere (for a detailed review, see Damasio, Tranel, Grabowskia, Adolphs, & Damasio, 2004).

P1: SQE
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In further support of the view that words activate perceptual representations, verifying the properties (denoted by adjectives) of objects (denoted by nouns) is faster when subsequent items remain in the same sensory modality. For example, verifying that a lemon is sour is faster after verifying that an apple is tart than after verifying that a lime is green, just as switching between modalities incurs processing costs in perceptual tasks (Pecher, Zeelenberg & Barsalou, 2003). If words activate traces of perceptual experience, then exposure to words should lead to the activation of the neural substrates that are also active when their referents are perceived. Neuroimaging research has produced just such evidence (e.g., Martin & Chao, 2001).

2.2. *Motor Traces*

The processing of words denoting objects makes available the affordances (i.e., possibilities for interaction) of those objects (Tucker & Ellis, 2004). Subjects viewed a series of pictures and judged whether the objects in the pictures were natural or manmade. The judgment was made by producing a power grip or a precision grip. Participants responded more quickly to objects that would be used with a power grip when their judgment response required a power grip, and they responded more quickly to objects that would be used with a precision grip when the judgment response required a precision grip. In a subsequent experiment, Tucker and Ellis (2004) asked participants to perform the same task, except that they responded to the words that label each of the objects rather than a picture. As before, participants responded to the words more quickly when the grip they used in making the response matched the grip they would use in interacting with the object.

Converging evidence for the activation of motor information on the processing of words comes from recent work in neuroscience. Regions of the brain responsible for the production of actions are active during the comprehension of action words (Hauk, Johnsrude, & Pulvermüller, 2004; for a review, see Pulvermüller, 1999). As expected on the mental simulation view, the patterns of activation that arise when processing words are somatotopically organized. The processing of words about hand actions, leg actions, and mouth actions activated different parts of the premotor cortex, each of which had been previously identified as responsible for executing hand, leg, and mouth actions.

2.3. *Other Traces*

The resituating power of words extends beyond the activation of perceptual and motor traces. For example, threat words, such as *destroy* and *mutilate* presented as part of a modified Stroop task, have been shown to activate bilateral amygdala regions to a greater extent than do neutral control words, thus implicating subcortical structures in semantic processing (Isenberg et al., 1999). The amygdala's role in emotional processing is well documented (e.g., LeDoux, 1995). In addition, activation was found in sensory-evaluative and motor-planning areas, areas that are normally activated when the organism senses danger. This is all the more noteworthy given that the subjects ostensive task was not comprehending words but naming the color in which they were shown.

3. Experiential Traces at the Sentence Level

As noted earlier, the experiential traces activated by individual words can be quite heterogeneous. Words may have several meanings, and traces relevant to each of these meanings are activated when the word is processed in the absence of a constraining context. For example, the word *nail* refers both to a body part (fingernail, toenail) and a metal fastener, and the processing of the word *nail* likely involves the activation of traces relevant to both senses of the word (at least initially). Sentences provide a constraining context that hones the retrieval of experiential traces for a given word (e.g.,

P1: SQE
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Tabossi, Colombo, & Job, 1987; Vu, Kellas, & Paul, 1998). Thus, in the sentence, "He used a hammer to drive the nail into the wall," the words *hammer* and *drive* create a particular context in which experiential traces relevant to *nail* will be retrieved. Under such conditions, the comprehender is likely to retrieve only those traces of *nail* that are relevant to the "metal fastener" sense of the word.

The preceding example highlights the fact that mental simulations evolve across time. As sensorimotor memory traces are retrieved, they produce a mental context that shapes the outcome of subsequent memory retrieval operations. For example, when one encounters the verb *throw*, many potential motor traces are activated. These traces are narrowed down when subsequent information in the sentence indicates which object is being thrown, where it is being thrown, and so on. In this sense, the construction of a mental simulation is akin to a constraint-satisfaction process.

3.1. *Perceptual Traces*

There is a growing body of evidence suggesting that perceptual information forms an important basis for the comprehension of sentences. In a series of studies, Zwaan and colleagues (Stanfield & Zwaan, 2001; Zwaan, Stanfield, & Yaxley, 2002) asked participants to perform a sentence-picture verification task. Participants would read sentences such as "John put the pencil in the cup." Subsequent to the sentence, participants saw a picture of a pencil and had to decide whether the object pictured appeared in the sentence (on critical trials, the answer was always "yes"). Participants respond to the picture more quickly when its orientation matched the orientation that the object would have in the situation described by the preceding sentence. For example, if the pencil was described as being in a cup, participants were faster to respond to a picture of a pencil oriented vertically than to respond to a picture of a pencil oriented horizontally. If the pencil was described as lying on a table, the opposite pattern was observed. Zwaan and colleagues showed that language comprehenders represented both the orientation and the shape of the objects described in the sentence.

The preceding experiments show that static perceptual information is retrieved during language comprehension. More recent studies have shown that the perceptual simulations that arise during language processing have dynamic components as well. Zwaan, Madden, Yaxley, and Aveyard (2004) asked participants to read sentences about objects moving towards them ("The first baseman threw you the ball") or away from them ("You threw the first baseman the ball"). After each sentence, participants saw two images presented in rapid succession, and had to decide whether the images were the same. For example, the participants saw two dots presented in succession. On critical trials, the second dot was either slightly larger (simulating motion toward the participant) or slightly smaller (simulating motion away from the participant) than the first dot. The change was small enough that it was not reliably detected by the participants. Responses were faster when the direction of motion implied by the dots matched the direction of motion described in the sentence.

A more recent set of experiments has shown that the actual mechanisms involved in auditory and visual processing are engaged during language comprehension. Kaschak et al. (2005) asked participants to listen to sentences describing motion in one of four directions: toward ("The car approached you"), away ("The car left you in the dust"), up ("The rocket blasted off"), and down ("The confetti fell on the parade"). At the same time, participants viewed black-and-white stimuli depicting motion in either the same direction as that described in the sentence (e.g., viewing a *toward* percept while hearing a *toward* sentence) or in the opposite direction as that described in the sentence (e.g., viewing an *away* percept while hearing a *toward* sentence). Participants made sensibility judgments more quickly for the critical sentences when the direction of motion in the percept mismatched the direction

P1: SQE
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of motion in the sentence. Kaschak et al. (2005) explained this pattern as the result of a competition for resources within the visual system. The *toward* percept is engaging the parts of the visual system that respond to *toward* motion, and thus it is difficult to use these parts of the visual system to simulate the *toward* motion described in the sentence. When the direction of motion in the percept and sentence mismatch, there is no such competition, and comprehension is more facile.

These findings have been extended to the auditory modality. Kaschak, Zwaan, Aveyard, and Yaxley (2006) asked participants to read sentences describing motion toward, away, up, or down while simultaneously listening to white noise manipulated to give the impression of motion in one of those four directions. As before, the direction of motion in the sound was either the same as the direction of motion in the sentence (toward-toward), or the opposite direction as that described in the sentence (toward-away). Again, responding was faster when the direction of motion in the percept mismatched the direction of motion in the sentence.

Interestingly, this pattern of data is reversed when the sentence and percept are presented in the same modality. The preceding experiments (in which responding was fastest in the mismatching conditions) all presented the linguistic input in a different modality than the percept. However, when participants processed auditorily presented sentences while also listening to the auditory motion stimuli, they responded more quickly when the direction of motion in the sentence matched the direction of motion in the percept. One explanation for this reversal in the pattern of response times is that presenting the sentences and percepts in a different modality allows both kinds of stimulus to be processed at the same time. This makes it possible to observe the competition for resources described previously. However, when the sentence and percept are presented in the same modality, the attentional demands of processing the sentence temporarily block the processing of the percept (for a discussion, see Lavie, 2005). Consequently, there is no competition for resources; instead, the direction of motion in the percept primes the comprehension of sentences describing motion in the same direction.

3.2. *Motor Traces*

The comprehension of sentences also involves the retrieval of motor traces. Klatzky, Pellegrino, McCloskey, and Doherty (1989) demonstrated that producing bodily postures (e.g., pinching the thumb and index finger together) facilitated the processing of sentences describing actions that required a similar body posture ("Aim a dart"). Thus, motor information can facilitate the comprehension of sentences. Glenberg and Kaschak (2002; see also Borreggine & Kaschak, 2006) showed that the converse is also true: processing sentences can facilitate motor responses. Participants read sentences describing an action that requires moving the arm toward the body ("Open the drawer") or away from the body ("Close the drawer"). The participants' task was to decide whether the sentences made sense. On critical trials, participants had to respond "yes" by making an arm motion either toward their body or away from their body. Half of the time the direction of the response matched the direction of motion in the sentence, and half of the time the direction of the response was the opposite of the direction of motion in the sentence. Participants responded more quickly when the direction of the "yes" response matched the direction of the action described by the sentence. Glenberg and Kaschak (2002) refer to this as the *action-sentence compatibility effect* (ACE).

Glenberg and Kaschak (2002) reported a reliable ACE across many kinds of sentences. Imperative sentences ("Open the door") and sentences about the transfer of concrete objects ("You gave Mike a pen") showed the ACE, as did sentences about abstract kinds of transfer ("You told Bill the story"). This latter finding suggests that the sensorimotor simulations underlie the comprehension not only of sentences about literal actions

P1: SQE
CUUS366-19 cuus366/Robbins ISBN: 978 0 521 84832 9 Top: 0.5in Gutter: 0.875in July 8, 2008 16:56

and events but also of sentences that involve abstraction.

The preceding studies used relatively coarse measures (e.g., whole sentence reading times) to assess the role of motor information in sentence processing. More recently, Zwaan and Taylor (2006) have begun investigating the motor resonance that occurs during on-line sentence processing. In one of their experiments they presented subjects with sentences such as "He / realized / that / the music / was / too loud/ so he / turned down / the /volume." The sentences were presented in segments and subjects progressed through the sentence by turning a knob, with each five degrees of rotation producing a new segment. Half the subjects turned the knob clockwise and the other half counterclockwise. Zwaan and Taylor found that when the direction of rotation implied by the sentence (e.g., turning down the volume implies counterclockwise rotation) matched the rotation the subjects themselves were making to read the sentence, reading times were shorter than when the two directions mismatched. To our knowledge, this is the first experiment to report on-line effects of motor resonance in language comprehension.

An interesting aspect of Zwaan and Taylor's (2006) results is that motor resonance was constrained to the so-called target region in the sentence (i.e., the segment at which the rotation was being described). This was the verb region in all critical sentences. This finding has two important implications. First, motor resonance occurs immediately upon encountering the relevant word or phrase. Second, it is short lived. The immediacy of motor resonance is consistent with constraint-based models of sentence processing (MacDonald et al., 1994; McRae et al., 1998). The finding of motor resonance being short lived could be due to the nature of the sentences. The verb phrase is followed by a noun phrase, which shifts the focus away from the action toward its result. It is possible that this attentional shift is responsible for the limited duration of motor resonance (e.g., MacWhinney, 2005). We are currently investigating this issue.

Buccino et al. (2005) have provided further insight into the role of motor traces in sentence processing. Using a combination of transcranial magnetic stimulation (TMS) and behavioral measures of sentence processing, Buccino and colleagues report that the processing of sentences about action using a particular effector (e.g., the hand) interferes with making responses with that same effector. Thus, when a hand motion must be programmed while comprehending a sentence about hand motions, there appears to be a competition for resources that slows the execution of the hand motion. Although this matter needs to be investigated in more detail, it puts the ACE and related effects in a different perspective. Simulating a sentence about hand motions appears to interfere with the production of hand motions. However, the interference may be less when the motion described in the sentence is congruent with the motion that needs to be produced.

3.3. *Other Traces*

Glenberg, Havas, Becker, and Rinck (2005) have reported experiments suggesting that systems involved in emotional responses are engaged during language comprehension. In a series of experiments, Glenberg et al. (2005) used the Strack procedure (Strack, Martin, & Stepper, 1988) to induce a particular mood in their participants. This procedure involves either holding a pen in your teeth to force the face into a smiling posture or holding a pen in your lips to force the face into a frowning posture. While in these emotion-inducing postures, participants read sentences that were positive or negative in emotional valence. Glenberg et al. (2005) report that participants respond more quickly to sentences when the emotional valence of the sentence matches their induced mood.

4. Resituating at the Discourse Level

Although it is useful to study the processing of words and sentences presented in

P1: SQE
CUUS366-19 cuus366/Robbins ISBN: 978 0 521 84832 9 Top: 0.5in Gutter: 0.875in July 8, 2008 16:56

isolation, most language-comprehension situations involve connected discourse. There is very little research on discourse comprehension from an embodied perspective. Just as motor resonance has been demonstrated at the word and the sentence level, it has been shown to occur at the level of discourse. Spivey and Geng (2001) had subjects listen to stories describing events that involved vertical or horizontal motion. They surreptitiously tracked the subjects' eye movements and found that vertical events tended to be associated with vertical eye movements and horizontal movements with horizontal eye movements, as if the subjects were directly observing these events (for an in-depth discussion of eye movements, see Spivey & Richardson, this volume).

Just as comprehenders use eye movements to trace the actions described in a discourse, they also use gestures to keep track of discourse entities across time. McNeil (1998) has shown that, in cases where a conversation involves events that take occur in different times and places, interlocutors use their gestures to indicate which events are being discussed. For example, events taking place in the present would be accompanied by gestures that are produced directly in front of the speaker's body, whereas events taking place in the past would be accompanied by gestures that are produced off to one side of the speaker's body. The spatial location of the gestures thus provides a reliable cue as to which set of events is being described in the current utterance. The gestures also facilitate transitions between talking about the past and present.

Another line of research has focused on cases in which the discourse structure deviates from everyday experience. If comprehenders process events conveyed though language the way they process actual events, then these deviations should bring about momentary disruptions of the comprehension process. For example, language allows us to deviate from the chronological and continuous flow of events we experience in real life. If we anticipate described events the way we anticipate actual events, then violations of temporal continuity should negatively affect on-line language comprehension. This has indeed been shown to be the case; reading times for sentences that violate chronology and continuity are longer than reading times for sentences that do not (e.g., Mandler, 1986; Zwaan, 1996; for extensive reviews, see Zwaan, 2004; Zwaan & Radvansky, 1998). These findings can be interpreted as consistent with the notion of presonance. On the basis of their experience with actual events, comprehenders expect by default that linguistically mediated events occurred chronologically and contiguously. Because this expectation is violated, there is a momentary slowdown of the comprehension process. However, given its exposure to violations of this expectation in language, the comprehension system quickly gets back on track.

The mental simulation view of language comprehension also predicts that the contents of the comprehender's working memory should reflect the accessibility of objects and events in the real world given our human sensory, attentional, and action-related limitations. For example, when observing objects and events in the real world, objects that are occluded are not as available for processing as objects that are not occluded. This leads to the prediction that working memory should contain the following:

- Present objects rather than absent objects
- Present features rather than absent features
- Close objects rather than distant objects
- Ongoing events rather than past events
- Current goals rather than past goals
- Visible entities rather than occluded entities

Actions in the real world should also be affected by the information that is retrieved in the service of mentally simulating a referent world. Several predictions follow from this claim. These predictions principally follow from the idea that the performance of

P1: SQE
CUUS366-19 cuus366/Robbins ISBN: 978 0 521 84832 9 Top: 0.5in Gutter: 0.875in July 8, 2008 16:56

the perceptual and motor systems should be affected by the requirements of the mental simulation. Evidence that the processing of words affects perceptual processes was reported by Richardson, Spivey, Barsalou, and McRae (2003). Evidence that motor processes are affected by sentence comprehension has been reported by Glenberg and Kaschak (2002), Zwaan and Taylor (2006), and Buccino et al. (2005). Additionally, we expect that when not otherwise engaged in the actual situation (e.g., when one is reading or deliberately trying to maintain eye contact with someone), eye movements should reflect the vicarious experience of the referent situation.

The assumptions that are generally made in discourse comprehension research are that (a) information that is currently in working memory is more accessible (i.e., more highly activated) than information that is not and, (b) when probed, more accessible information will yield faster responses than less accessible information. Therefore, the presentation of probe words associated with the contents of working memory should facilitate responses. In accordance with this logic, various studies have demonstrated that the contents of working memory during comprehension reflect the nature of the described situation. Probe-word responses are faster when the probe refers to

- A present entity rather than an absent entity (Anderson, Garrod, & Sanford, 1983; Carreiras, Carriedo, Alonso, & Fernandez, 1997).
- A present rather than an absent feature (Kaup & Zwaan, 2003).
- A present object rather than a distant object (Glenberg, Meyer, & Lindem, 1987; Morrow, Bower, & Greenspan, 1989; Morrow, Greenspan, & Bower, 1987; Rinck & Bower, 2000).
- An ongoing event rather than a past event (Zwaan, 1996; Zwaan, Madden, & Whitten, 2000).
- A current goal rather than an accomplished one (Trabasso & Suh, 1993).
- A visible entity rather than an occluded one (Horton & Rapp, 2002).

As mentioned earlier, there is also evidence that comprehenders assume the spatial perspective of a protagonist in the story (Bower, Black, & Turner, 1979; Bryant, Tversky, & Franklin, 1992; Franklin & Tversky, 1990; Morrow & Clark, 1988; Rall & Harris, 2000).

5. Conclusions and Outlook

There is a good deal of evidence that language processing brings about the presonance of perceptual, motoric, and experiential traces in the comprehender. This evidence has been found at the word, sentence, and discourse levels. We argue that this evidence can be coherently explained by assuming that language comprehension is grounded in the same neural systems that are used to perceive, plan, and take action in the external world. In this way, the comprehension of language involves the vicarious experiencing of the people, objects, emotions, and events that are described in the text. More broadly, just as our ability to plan and take action in the world relies on the ability to anticipate likely changes that will occur in the environment, we argue that an essential part of the language comprehension process is the ability to anticipate what is coming next, both in the linguistic input and in the situations that are being described. This process of presonance is immediate and effortless. It allows us to resituate ourselves and vicariously experience (and learn from) events that have happened in situations other than the one we currently find ourselves in.

Whereas we find much promise in this general approach to language comprehension, significant research remains to be done on virtually all fronts. There is a relative dearth of research on how sensorimotor information is retrieved and used during online sentence comprehension. There has also been little work considering how known elements of perceptual or motoric processing systems can be integrated with an account that explains the moment-by-moment comprehension of sentences. Finally, very little effort has been put forth to determine how and when sensorimotor information might be retrieved and used during the comprehension of language in more naturalistic tasks (e.g., tasks in which reading does not involve twisting a knob or moving one's arm or viewing some sort of percept). These questions highlight the fact that we are only at the beginning of the process of building a sensorimotor account of language processing. As we look to the future, we see the development of a theory that firmly grounds the comprehension of language in our ability to plan and act and that views language not as a something that is special and distinct from the rest of cognition but as something that is a natural extension of the cognitive processes needed to act successfully in the external world.

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References

Anderson, A., Garrod, S. C., & Sanford, A. J. (1983). The accessibility of pronominal antecedents as a function of episode shifts in narrative text. *Quarterly Journal of Experimental Psychology*, *35A*, 427–440.

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*, 577–660.

Barsalou, L. W. (2005). Situated conceptualization. In H. Cohen & C. Lefebvre (Eds.), *Handbook of categorization in cognitive science* (pp. 619–650). St. Louis: Elsevier.

Borreggine, K. L., & Kaschak, M. P. (2006). The action-sentence compatibility effect: It's all in the timing. *Cognitive Science*, 30(6), 1097–1112.

Bower, G. H., Black, J. B., & Turner, T. J. (1979). Scripts in memory for text. *Cognitive Psychology*, *11*, 177–220.

Bryant, D. J., Tversky, B., & Franklin, N. (1992). Internal and external spatial frameworks for representing described scenes. *Journal of Memory and Language*, *31*, 74–98.

Buccino, G., Riggio, L., Mellia, G., Binkofski, F, Gallese, V., & Rizzolatti, G. (2005). Listening to action-related sentences modulates the activity of the motor system: A combined TMS and behavioral study. *Cognitive Brain Research*, *24*, 355–363.

Carreiras, M., Carriedo, N., Alonso, M. A., & Fernandez, A. (1997). The role of verbal tense and verbal aspect in the foregrounding of information in reading. *Memory and Cognition*, *23*, 438–446.

Chambers, C. G., Tanenhaus, M. K., & Magnuson, J. S. (2004). Actions and affordances in syntactic ambiguity resolution. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*, 687–696.

Damasio, H., Tranel, D., Grabowskia, T., Adolphs, R., & Damasio, A. (2004). Neural systems behind word and concept retrieval. *Cognition*, 92, 179–229.

Flanagan, J. R., & Johansson, R. S. (2003). Action plans used in action observation. *Nature*, *424*, 769–771.

Fowler, C. A. (1996). Listeners do hear sounds, not tongues. *Journal of the Acoustical Society of America*, 99, 1730–1741.

Franklin, N., & Tversky, B. (1990). Searching imagined environments. *Journal of Experimental Psychology: General*, *119*, 63–76.

Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences*, *20*, 1–19.

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

Glenberg, A. M., Havas, D., Becker, R., & Rinck, M. (2005). Grounding language in bodily states: The case for emotion. In R. A. Zwaan & D. Pecher (Eds.), *The grounding of cognition: The role of perception and action in memory, language, and thinking* (pp. 115–128). Cambridge: Cambridge University Press.

Glenberg, A. M., Meyer, M., & Lindem, K. (1987). Mental models contribute to foregrounding during text comprehension. *Journal of Memory and Language*, *26*, 69–83.

Goldberg, A. E. (1995). *Constructions: A construction grammar approach to argument structure*. Chicago: University of Chicago Press.

Harnad, S. (1990). The symbol grounding problem. *Physica D*, *42*, 335–346.

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

Hess, D. J., Foss, D. J., & Carroll, P. (1995). Effects of global and local context on lexical processing during language comprehension. *Journal of Experimental Psychology: General*, *124*, 62–82.

Hintzman, D. L. (1986). "Schema-abstraction" in a multiple trace model. *Psychological Review*, *93*, 411–428.

Horton, W. S., & Rapp, D. N. (2002). Occlusion and accessibility of information is narrative comprehension. *Psychonomic Bulletin & Review*, *10*, 104–109.

Isenberg, N., Silbersweig, D., Engelien, A., Emmerich, K., Malavade, K., Benti, B., et al. (1999). Linguistic threat activates the human amygdala. *Proceedings of the National Academy of Sciences*, *96*, 10456–10459.

Jurafsky, D. (1996). A probabilistic model of lexical and syntactic access and disambiguation. *Cognitive Science*, *20*, 137–194.

Kaschak, M. P., Madden, C. J., Therriault, D. J., Yaxley, R. H., Aveyard, M., Blanchard, A. A., et al. (2005). Perception of motion affects language processing. *Cognition*, *94*, B79–B89.

Kaschak, M. P., Zwaan, R. A., Aveyard, M., & Yaxley, R. H. (2006). Perception of auditory motion affects language processing. *Cognitive Science*, *30*(4), 733–734.

Kaup, B., & Zwaan, R.A. (2003). Effects of negation and situational presence on the accessibility of text information. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*, 439–446.

Klatzky, R. L., Pellegrino, J. W., McCloskey, B. P., & Doherty, S. (1989). Can you squeeze a tomato? The role of motor representations in semantic sensibility judgements. *Journal of Memory and Language*, *28*, 56–77.

Lavie, N. (2005). Distracted and confused? Selective attention under load. *Trends in Cognitive Sciences*, *9*, 75–82.

LeDoux, J. E. (1995). Emotion: Clues from the brain. *Annual Review of Psychology*, *46*, 209–235.

MacDonald, M. C., Pearlmutter, N. J., & Seidenberg, M. S. (1994). Lexical nature of syntactic ambiguity resolution. *Psychological Review*, *101*, 676–703.

MacWhinney, B. (2005). The emergence of grammar from perspective taking. In D. Pecher & R. A. Zwaan (Eds.), *Grounding cognition: The role of perception and action in memory, language, and thinking* (pp. 198–223). Cambridge: Cambridge University Press.

Mandler, J. M. (1986). On the comprehension of temporal order. *Language and Cognitive Processes*, *1*, 309–320.

Martin, A., & Chao, L. L. (2001). Semantic memory and the brain: Structure and process. *Current Opinion in Neurobiology*, *11*, 194–201.

Masur, E. F. (1997). Maternal labeling of novel and familiar objects: Implications for children's development of lexical constraints. *Journal of Child Language*, *24*, 427–439.

McNeill, D. (1998). Speech and gesture integration. In J. M. Iverson & S. Goldin-Meadow (Eds.), *The nature and functions of gesture in children's communication: New directions for child development* (No. 9, pp. 11–27). San Francisco: Jossey-Bass.

McRae, K., Spivey-Knowlton, M. J., & Tanenhaus, M. K. (1998). Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. *Journal of Memory and Language*, *38*, 283–312.

Morrow, D. G., Bower, G. H., & Greenspan, S. L. (1989). Updating situation models during narrative comprehension. *Journal of Memory and Language*, *28*, 292–312.

Morrow, D. G., & Clark, H. H. (1988). Interpreting words in spatial descriptions. *Language and Cognitive Processes*, *3*, 275–291.

Morrow, D. G., Greenspan, S. E., & Bower, G. H. (1987). Accessibility and situation models in narrative comprehension. *Journal of Memory and Language*, *26*, 165–187.

Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2003). Verifying the properties of object concepts across different modalities produces switching costs. *Psychological Science*, *14*, 119–129.

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CUUS366-19 cuus366/Robbins ISBN: 978 0 521 84832 9 Top: 0.5in Gutter: 0.875in July 8, 2008 16:56

Pickering, M. J., & Garrod, S. (2004). Toward a mechanistic psychology of dialogue. *Behavioral and Brain Sciences*, *27*, 169–226.

Porter, R., & Lubker, J. (1980). Rapid reproduction of vowel-vowel sequences: Evidence for a fast and direct acoustic-motoric linkage in speech. *Journal of Speech and Hearing Research*, *23*, 593–602.

Pulvermüller, F. (1999). Words in the brain's language. *Behavioral and Brain Sciences*, *22*, 253–336.

Rall, J., & Harris, P. L. (2000). In Cinderella's slippers? Story comprehension from the protagonist's point of view. *Developmental Psychology*, *36*, 202–208.

Richardson, D. C., Spivey, M. J., Barsalou, L. W., & McRae, K. (2003). Spatial representations activated during real-time comprehension of verbs. *Cognitive Science*, *27*, 767–780.

Rinck, M., & Bower, G. H. (2000). Temporal and spatial distance in situation models. *Memory and Cognition*, *28*, 1310–1320.

Searle, J. R. (1980). Minds, brains, and programs. *Behavioral and Brain Sciences*, *3*, 417–424.

Spivey, M. J., & Geng, J. J. (2001). Oculomotor mechanisms activated by imagery and memory: Eye movements to absent objects. *Psychological Research*, *65*, 235–241.

Spivey, M. J., & Tanenhaus, M. K. (1998). Syntactic ambiguity resolution in discourse: Modeling the effects of referential context and lexical frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 1521–1543.

Stanfield, R. A., & Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science*, *12*(2), 153–156.

Strack, F., Martin, L., & Stepper, S. (1988). Inhibiting and facilitating conditions of the human smile: A nonobtrusive test of the facial feedback hypothesis. *Journal of Personality and Social Psychology*, *54*, 768–777.

Tabossi, P., Colombo, L., & Job, R. (1987). Accessing lexical ambiguity: Effects of context and dominance. *Psychological Research*, *49*, 161–167.

Tomasello, M. (2003). *Constructing a language: A usage-based theory of language acquisition*. Cambridge, MA: Harvard University Press.

Townsend, D. J., & Bever, T. G. (2001). *Sentence comprehension: The integration of habits and rules*. Cambridge, MA: MIT Press.

Trabasso, T., & Suh, S. (1993). Understanding text: Achieving explanatory coherence through on-line inferences and mental operations in working memory. *Discourse Processes*, *16*, 3–34.

Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica*, *116*, 185–203.

van Berkum, J. J. A., Brown, C. M., Zwitserlood, P., Kooijman, V., & Hagoort, P. (2005). Anticipating upcoming words in discourse: Evidence from ERPs and reading times. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*, 443–467.

van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York: Academic Press.

Vu, H., Kellas, G., & Paul, S. T. (1998). Sources of sentence constraint on lexical ambiguity resolution. *Memory and cognition*, *26*, 979–1001.

Wolpert, D. M., Doya, K., & Kawato, M. (2003). A unifying computational framework for motor control and social interaction. *Philosophical Transactions of the Royal Society*, 358, 593–602.

Zwaan, R. A. (1994). Effect of genre expectations on text comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*, 920–933.

Zwaan, R. A. (1996). Processing narrative time shifts. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 1196–1207.

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* (Vol. 44, pp. 35–62). New York: Academic Press.

Zwaan, R. A., & Madden, C. J. (2004). Updating situation models. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 30, 283–288.

Zwaan, R. A., Madden, C. J., & Whitten, S. N. (2000). The presence of an event in the narrated situation affects its activation. *Memory & Cognition*, *28*, 1022–1028.

Zwaan, R. A., Madden, C. J., Yaxley, R. H., & Aveyard, M. E. (2004). Moving words: Dynamic mental representations in language comprehension. *Cognitive Science*, *28*, 611–619.

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

Zwaan, R. A., & Rapp, D. N. (2006). Discourse comprehension. In M. A. Gernsbacher & M.

P1: SQE
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J. Traxler (Eds.), *Handbook of psycholinguistics* (2nd ed.) (pp. 725–764). San Diego, CA: Elsevier.

Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science*, *13*(2), 168–171.

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

Zwaan R. A., & Yaxley, R. H. (2004). Lateralization of object-shape information in semantic processing. *Cognition*, *94*, B35–B43.