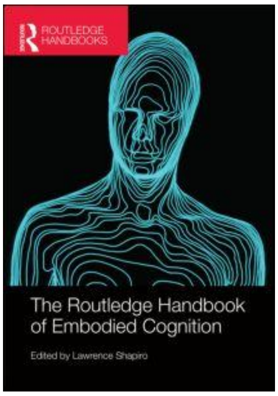

The Routledge Handbook of Embodied Cognition

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Embodiment and Language Comprehension

Publication details
https://www.routledgehandbooks.com/doi/10.4324/9781315775845.ch12
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Published online on: 01 May 2014

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EMBODIMENT AND LANGUAGE COMPREHENSION

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The ability to create and convey meaning is an ability that lies at the heart of the human ability to use language. The creation of meaning through language is central to our capacity to accomplish a range of intra- and interpersonal goals, and therefore a theory of "meaning making" (and, "meaning apprehension") must have a key place in theories that explain the acquisition, comprehension, and production of language (Glenberg and Robertson, 2000). The goal of this chapter is to discuss one account of how language conveys meaning, the *embodied approach to language comprehension*. The aspect of the embodied approach that has received the most empirical and theoretical attention is the claim that the comprehension of sentences such as, "Meghan gave Michael a pen," involves the construction of internal sensorimotor simulations of the content of the sentence. In this case, one might simulate a male and a female, and the arm action involved in transferring a pen from one person to another (e.g. Glenberg and Kaschak, 2002). We discuss the evidence for this claim, as well as criticisms of this embodied position. We also draw on recent proposals (e.g. Pickering and Garrod, 2013) to consider other ways that language can be considered "embodied."

The symbol grounding problem

The phrase *embodied approach to language comprehension* is most often taken as a reference to the claim that linguistic meaning arises from sensorimotor simulations of the actions, events, and states that are described in language. Thus, comprehending an action verb such as *give* or *kick* involves the recruitment of the motor system to simulate giving and kicking actions (e.g. Glenberg and Kaschak, 2002; Hauk, Johnsrude, and Pulvermüller, 2004), understanding words and phrases describing visual motion involves the recruitment of the visual system to simulate moving objects (e.g. Meteyard, Bahrami, and Vigliocco, 2007), and understanding language about emotion involves internal simulation of emotional states (e.g. Havas, Glenberg, and Rinck, 2007). This claim of the embodied approach is supported by a growing body of evidence (reviewed in Fischer and Zwaan, 2008). Before discussing this evidence, however, we discuss the embodied approach within the context of a broader theoretical issue surrounding linguistic meaning, namely the *symbol grounding problem* (e.g. Harnad, 1990; Searle, 1980)

We describe the symbol grounding problem in terms of Harnad's (1990) Chinese airport example. Imagine that you have just disembarked from a plane in China. You do not understand

Chinese, but have a Chinese dictionary. You decide to find the baggage claim, and look at the sign hanging from the ceiling for directions. The sign is written in Chinese, so you open the dictionary to find the first word on the sign. You find the word, and find that its definition is written in Chinese. No problem, you think, you'll just look up the first word of the definition in the dictionary. You do so, and find that the word is defined in Chinese as well. It is clear that no matter how much time you spend with the sign and the dictionary, you will never figure out what the words on the sign mean. This is the essence of the symbol grounding problem. Symbols that are abstract and arbitrary (such as words, whose form is abstracted away from, and arbitrarily related to, the things to which they refer) cannot be understood solely through their connection to other abstract, arbitrary symbols. They can only be understood by being grounded in some other representational format that is understood in and of itself. In the case of the Chinese airport, a picture of a suitcase along with an arrow pointing down one corridor would provide the grounding needed to understand the sign. Although you do not understand the words, you do understand the pictures, and can use this knowledge to develop an understanding of what the words mean. With respect to language, the embodied approach claims that the abstract, arbitrary symbols of language become meaningful by being grounded in knowledge about our bodies, and how our bodies interact with the world.

The symbol grounding problem provided an important impetus for the development of an embodied approach to language comprehension (e.g. Glenberg and Robertson, 2000). The embodied approach resolves the symbol grounding problem by asserting that abstract, arbitrary linguistic forms (e.g. words, phrases, abstract syntactic templates) are understood through their grounding in our bodies' systems of perception and action planning (Glenberg, 1997). To illustrate, consider the meaning of the word *violin*. Embodied approaches claim that the meaning of this word is rooted in sensorimotor experience with violins – perceptual and motor records of what they look like, what they sound like, what it feels like to hold one and draw a bow across its strings (if you have ever done so), and what it looks like to watch someone else play the instrument (which may be especially important if you have never done so yourself). In Barsalou's (1999) proposal, processing the word *violin* involves the recruitment of these perceptual records to internally simulate what violins look like, how they are played, the kinds of sound they make, and so on. These simulations are the basis of linguistic meaning. The simulations are understood in the same way as one understands real objects, actions, and events in the external world.

Claiming that embodied approaches resolve the symbol grounding problem relies on the assumption that we have a fundamental understanding of our bodies and how they act in, and interact with, the external environment. This claim resonates well with thinking about the evolution of cognition. It has been noted that the evolution of nervous systems is rooted in the need for organisms to move (*cognition is for action*; Wolpert, Ghahramani, and Flanagan, 2001). In evolutionary terms, there is a close relationship between body morphology, nervous system characteristics, and cognitive abilities (e.g. MacIver, 2009). For example, body symmetry (found in virtually all animals) is a characteristic that allowed for increased forward mobility, and also presaged the clustering of sense organs around the anterior end of the organism, which led to the development of brains (e.g. Grabowsky, 1994; Paulin, 2005; MacIver, 2009). The evolution of sense organs and nervous systems was strongly influenced by the nature of the organisms' bodies and how that body interacted with the environment (e.g. Engelhaaf *et al.*, 2002). MacIver (2009) notes that the ability to perceive information from the distal environment allowed for the development of more complex forms of cognition (such as planning), but these more complex forms of cognition are rooted in existing systems that allow us to act on our environment (see Walsh, 2003, for a discussion of how understanding abstractions such as time is grounded in the neural circuitry involved in reaching for and grasping objects). Thus, our cognitive abilities (including the use of language) are inextricably bound up in a nervous system that evolved for the purpose of taking successful action in the environment (see Glenberg, 1997, for a discussion of this point).

It is worth noting that whereas the embodied approach has a straightforward approach to resolving the symbol grounding problem, other approaches to linguistic meaning that are on offer in the cognitive science community (e.g. semantic networks; the approaches represented by formalisms such as Landauer and Dumais' [1997] latent semantic analysis) either completely fail to resolve this problem or resolve the problem by acknowledging the need for some layer of "embodied" (i.e. perceptual or motor) representations within a larger semantic system. Space constraints do not permit a full airing of this issue (see de Vega, Glenberg, and Graesser, 2008, for a thorough approach to the matter), but it is our sense that a consideration of the symbol grounding problem provides a firm basis for why something like an embodied approach to language comprehension is needed to explain linguistic meaning – if linguistic symbols are not grounded in systems of perception and action planning, it is difficult to understand how they could convey meaning.

Embodiment and language comprehension: empirical studies

Embodied approaches to language comprehension hold that language is understood through the construction of sensorimotor simulations of the content of the linguistic input (e.g. Glenberg and Kaschak, 2002; Stanfield and Zwaan, 2001). This claim has been tested extensively over the past decade. In the following pages, we provide a selective overview of this empirical work.

Motor simulations

A major line of research on the embodiment of language comprehension involves the role that motor simulations play in the comprehension of words and sentences. An early example of this work is presented by Glenberg and Kaschak (2002). They asked participants to read (and make sensibility judgments on) sentences such as, "Meghan gave you a pen" or "You gave Meghan a pen." The first sentence describes action toward the body (you are receiving the pen), and the second sentence describes action away from the body (you are giving the pen away). To make sensibility judgments, participants needed to either produce an action toward their body (moving toward their body to press a button) or produce an action away from their body (moving away from the body to press a button). Participants were faster to execute the actions when the direction of action described in the sentence (toward or away from the body) matched the direction of action needed to make the sensibility judgment response (toward or away from the body). That is, the processing of a sentence about action affected the comprehender's ability to plan and execute action in the external environment.

A number of subsequent studies have expanded upon Glenberg and Kaschak's (2002) initial findings. In one series of studies, Zwaan and Taylor (2006) asked participants to read sentences while turning a knob to get from one phrase in the sentence to the next. They found that not only does one find motor-compatibility effects when participants produce a motor response after comprehending an entire sentence (as in Glenberg and Kaschak, 2002), but that one also finds localized motor-compatibility effects during the online processing of the sentence. Zwaan and Taylor (2006) report that motor effects arise when participants are reading the verb of the sentence, or when reading a word (such as an adverb) that modifies the way in which the action of the verb is being executed (Taylor and Zwaan, 2008). Thus, there seems to be relatively localized motor activity during the online comprehension of a sentence (Zwaan and Taylor, 2006; Taylor and Zwaan, 2008; Glenberg *et al.*, 2008), as well as motor activity associated with the processing of an entire sentence (Glenberg and Kaschak, 2002; Borreggine and Kaschak, 2006).

The nature of the motor activity that arises during language comprehension has been further clarified in studies reported by Bub and Masson (2010; Masson, Bub, and Warren, 2008). Using a response device called the Graspasaurus, Bub and Masson examined the extent to which the processing of nouns (e.g. *calculator*) activates *functional* motor gestures (e.g. using the pointer finger to poke the keys of the calculator) and *volumetric* motor gestures (e.g. using an open hand grasp to pick the calculator up). Bub and Masson (2010) report that both functional and volumetric gestures are activated online during sentence processing, but only functional gestures remain active once the sentence has ended. Furthermore, Masson *et al.* (2008) report that functional gestures are activated even when the sentence does not describe explicit action on an object (e.g. "The man looked at the calculator"). Taken together, the various findings reported here suggest that motor information is elicited by the processing of both nouns and verbs, that this information is elicited during online comprehension, and persists to become a part of the final interpretation of the sentence.

The behavioral studies described above are complemented by the results of studies using fMRI and EEG techniques to observe motor activity during the comprehension of language (see Pulvermüller, 1999, for an overview). The most well-known finding in this area is Hauk *et al.*'s (2004) report that the processing of words such as *pick*, *kick*, and *lick* elicits motor activity in the hand, foot, and mouth areas of the motor cortex. A similar degree of motor specificity was reported by Tettamanti *et al.* (2005) and Buccino *et al.* (2005). Thus, there is a strong empirical case to be made that the comprehension of language about action involves the use of the neural systems that are involved in action planning and execution.

Perceptual simulations

A second major area of exploration for the embodied perspective has examined the perceptual simulations that arise during language processing. Zwaan and colleagues (Stanfield and Zwaan, 2001; Zwaan, Stanfield, and Yaxley, 2002; Zwaan, Madden, Yaxley, and Aveyard, 2004) used a paradigm in which participants read a sentence that specified some visual content (e.g. reading, "The eagle is in the sky," should elicit a simulation of an eagle with outstretched wings). After reading the sentence, the participants viewed a picture of an object (e.g. an eagle), and had to indicate whether the object depicts something that was mentioned in the sentence. Zwaan and colleagues report that responses to the picture are faster when the content of the picture matches the content of the sentence (e.g. a picture of an eagle with outstretched wings) than when the picture mismatches the content of the sentence (e.g. a picture of an eagle with wings folded in).

Kaschak *et al.* (2005) report another set of experiments in which participants process sentences about visual motion (e.g. "The squirrel ran away from you" describes visual motion away from the body) while also viewing stimuli depicting motion. They find that participants are faster to respond to sentences when the concurrently presented visual stimulus depicts motion in the opposite direction as the sentences (e.g. watching motion toward the body, while processing a sentence about motion away from the body). The conflict that arises when the direction of the visual stimulus and the direction of motion in the sentence are the same is taken as evidence that the comprehension of sentences about visual motion involves the use of the neural mechanisms that are involved in the perception of motion in the external environment. A number of subsequent studies have produced evidence that the processing of language about motion affects, and is affected by, the processing of visual stimuli (e.g. Bergen, Lindsay, Matlock, and Narayanan, 2007; Richardson and Matlock, 2007; Meteyard *et al.*, 2007). As in the case of motor simulations, the behavioral evidence for perceptual simulations is complemented by findings from neuroscience demonstrating that the processing of language about perceptual characteristics elicits activity in the neural regions associated with the processing of distal perceptual stimuli (see Martin, 2007, and Binder, Desai, Graves, and Conant, 2009, for reviews).

Simulation of emotion and abstractions

A more recent development in the embodied approach to language comprehension is to consider how embodied representations underlie the understanding of language about emotions and other kinds of abstract concepts. The simulation of emotion has been tackled by Glenberg and colleagues (Havas *et al.*, 2007; Havas, Glenberg, Gutowski, Lucarelli, and Davidson, 2010). One particularly striking finding from this program of research is reported by Havas *et al.* (2010). Their participants received injections of Botox in the muscles involved in frowning. These participants subsequently showed impairment in the comprehension of sentences involving negative emotion. Interfering with one's ability to physically express emotion thus interferes with one's ability to process sentences that trade on that emotion.

Much has been written about how embodied approaches can handle the understanding of abstract concepts (e.g. Lakoff and Johnson, 1980; Gibbs, 2011; Casasanto and Boroditsky, 2008; Barsalou, 1999). The general idea behind this work has been to illustrate how particular kinds of abstraction (e.g. emotions, social power, and time, to name a few) are grounded in particular domains of concrete experience (see, for example, Lakoff and Johnson's [1980] influential "conceptual metaphor" approach). As one example of this, a series of recent studies have demonstrated that the comprehension of language about time (e.g. shifts between the past and the future) is grounded in representations of the space around one's body (e.g. Santiago, Lupianez, Perez, and Fuenes, 2007; Ulrich *et al.*, 2012; Sell and Kaschak, 2011). Santiago *et al.* (2007) report that the understanding of past and future tense is grounded in the left-right axis (past = left, future = right). Sell and Kaschak (2011) report a different mapping of space and time (e.g. future is in front of you, past is behind you; see also Boroditsky and Ramscar, 2002). There is clearly more to understand with respect to how spatial representations are used to ground the comprehension of abstractions such as time, but these findings nonetheless provide evidence that the understanding of concrete domains of experience (e.g. moving in the space around one's body) provides a basis for understanding language about abstractions such as time.

Embodiment and language comprehension: criticisms and alternatives

Although the embodied approach to language comprehension (and to cognition in general) has received a growing amount of support in the literature, embodied approaches have not been without their critics. The critics, while acknowledging that there is an empirical case for claiming that perceptual and motor systems are activated during language processing, typically argue that the embodied hypothesis is incomplete, and that the sensorimotor representations invoked by embodiment theorists must be incorporated into a broader approach that contains both "embodied" and "abstract, symbolic" representations (e.g. Mahon and Caramazza, 2008; Louwerse, 2008).

Mahon and Caramazza (2008) presented a "grounding by interaction" view which posits that conceptual knowledge consists of both sensorimotor representations and abstract, symbolic representations abstracted from experience. To borrow an example from their paper, consider the concept *dog*. We have sensorimotor experiences with specific dogs (e.g. retrievers and Dalmatians), but these experiences do not constitute the concept *dog*. Rather, the concept resides on an abstract layer of representation that generalizes across these experiences. Mahon and Caramazza (2008) further suggest that the extant literature on "embodiment" effects cannot distinguish between a view in which sensorimotor representations are directly activated as a function of linguistic input and a view in which linguistic input activates abstract, symbolic representations, sensorimotor representations, or both, and that activation rapidly cascades between the two types of representation.

We are sympathetic to Mahon and Caramazza's (2008) view that our understanding of concepts such as *dog*, *violin*, or *beauty* is richer than what is encapsulated in the view of embodiment detailed throughout this chapter. However, given the deep and well-noted problems with abstract symbolic representational schemes (e.g. Barsalou, 1993; Harnad, 1990; Glenberg and Robertson, 2000), it is not clear to us that Mahon and Caramazza's (2008) proposal represents a promising route forward. For example, they assert that there is no set of particular sensorimotor simulations that can capture all the meanings and uses of the word *beautiful*. This may be, but stipulating an ill-defined "abstract" layer of representation does not strike us as moving toward a workable solution.

Louwerse (2008; Louwerse and Connell, 2011) has similarly proposed a symbol interdependency hypothesis, which posits that linguistic meaning derives from both abstract, symbolic information (in this case, statistical co-occurrences between words) and sensorimotor representations. The symbolic, statistical information is presumed to be used early in the processing of language (providing a good-enough, surface-level interpretation of the linguistic input), and sensorimotor information is presumed to be used later in the processing of language (providing a more detailed representation of the content of the language). As above, we are sympathetic to the approach represented by this hypothesis; indeed, we feel that it is past time for embodied theories of language comprehension to be integrated more fully with the "statistical" or constraint-based approaches to sentence processing found in psycholinguistics (e.g. MacDonald, Pearlmutter, and Seidenberg, 1994). At the same time, it is not clear that the claims made by this approach are actually problematic for embodiment. One aspect of this account – that sensorimotor representations are accessed late in the comprehension process – is contradicted by the data. Pulvermüller (1999), Boulenger *et al.* (2006), and Bub and Masson (2010), among others, all show that motor activity occurs rapidly during online language processing. A second way in which this account is misguided is that it presumes that "statistical" information must necessarily be "abstract" or "symbolic," and not embodied. This need not be the case, especially when one considers that the statistical information is essentially co-occurrences of perceptual and motoric events (e.g. speech production, hearing or reading words).

Embodiment and language comprehension: beyond sensorimotor simulations

We are skeptical that the hybrid embodied-symbolic accounts sketched in the preceding section will turn out, in the long run, to be viable theoretical accounts of language comprehension. Nonetheless, the criticism that the embodied approach to language comprehension is incomplete in its ability to explain the multiple facets of linguistic meaning has validity. Answering this criticism within the framework of an embodied perspective requires thinking of the embodiment of language in broader terms than equating embodiment with sensorimotor simulations.

The chapters in this volume discuss embodiment from a variety of perspectives, some sticking close to the "embodiment as simulation" view and others embracing an approach to embodiment that emphasizes the "situated" nature of cognition. In the former case, the focus is on how specific cognitive content is represented (e.g. what do we know about violins?). In the latter case, there is a focus on acting in the environment in a broader sense. Thinking about language in this way, we can consider that language comprehenders know things about the objects and actions that are described by language, and also about language as an act in and of itself. That is, we know about the physical act of speaking (or writing), and we know how to use these sequences of action to accomplish specific goals (e.g. speech acts; Austin, 1960).

Pickering and Garrod (2013) have recently explicated this idea by distinguishing between *embodiment in content* (i.e. simulations of the contents of language) and *embodiment in form* (i.e. knowledge of how language is produced, and the role that this plays in the production and comprehension of language). Just as we may understand others' actions in terms of the possible actions of our own bodies (e.g. Rizzolatti, Sinigaglia, and Anderson, 2008), one component of our understanding of language may be our knowledge of how to physically produce language, and knowledge of patterns of speech that we have previously both heard and produced ourselves. In this way, information that is relevant to the interpretation of language, such as intonation contours, tone of voice, and the like, but outside of the purview of sensorimotor simulations (as they are normally construed), may still be seen as falling within the scope of an embodied account of language comprehension. When embodiment is considered from this broader perspective, we believe it will be possible to subsume the observations that Mahon and Caramazza (2008) and Louwerse and colleagues (e.g. Louwerse 2008) considered to be problematic for the simulation view of embodiment under a more expansive of this theoretical perspective.

References

Austin, J. L. (1960). *How to do things with words*. Oxford: Oxford University Press.

Barsalou, L. W. (1993). Flexibility, structure, and linguistic vagary in concepts: Manifestations of a compositional system of perceptual symbols. In A. C. Collins, S. E. Gathercole, and M. A. Conway (Eds.), *Theories of memory* (pp. 29–101). London: Lawrence Erlbaum Associates.

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

Bergen, B., Lindsay, S., Matlock, T., and Narayanan, S. (2007). Spatial and linguistic aspects of visual imagery in sentence comprehension. *Cognitive Science, 31*, 733–64.

Binder, J. R., Desai, R. H., Graves, W. W., and Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cerebral Cortex*, *19*, 2767–96.

Boroditsky, L., and Ramscar, M. (2002). The roles of body and mind in abstract thought. *Psychological Science, 13*, 185–89.

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

Boulenger, V., Roy, A. C., Paulignan, Y., Deprez, V., Jeannerod, M., and Nazir, T. A. (2006). Cross-talk between language processes and overt motor behavior in the first 200 ms of processing. *Journal of Cognitive Neuroscience, 18,* 1607–15.

Bub, D. N., and Masson, M. E. J. (2010). On the nature of hand-action representations evoked during written sentence comprehension. *Cognition*, *116*, 394–408.

Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., and 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*, 355–63.

Casasanto, D., and Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition, 106*, 579–93.

de Vega, M., Glenberg, A. M., and Graesser, A. C. (Eds.) (2008). *Symbols, embodiment, and meaning*. Oxford: Oxford University Press.

Engelhaaf, M., Kern, R., Krapp, H. G., Kretzberg, J., Kurtz, R., and Warzecha, A. K. (2002). Neural encoding of behaviorally relevant visual-motion information in the fly. *Trends in Neurosciences, 25*, 96–102.

Fischer, M. H., and Zwaan, R. A. (2008). Embodied language—A review of the role of the motor system in language comprehension. *Quarterly Journal of Experimental Psychology, 61*, 825–50.

Gibbs, R. W. (2011). Evaluating conceptual metaphor theory. *Discourse Processes, 48*, 529–62.

Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences, 20*, 1–55.

Glenberg, A. M., and Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9*, 558–65.

Glenberg, A. M., and Robertson, D. A. (2000). Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. *Journal of Memory and Language*, *43*, 379–401.

Glenberg, A. M., Sato, M., Cattaneo, L., Riggio, L., Palumbo, D., and Buccino, G. (2008). Processing abstract language modulates motor system activity. *Quarterly Journal of Experimental Psychology, 61*, 905–19.

Grabowsky, G. L. (1994). Symmetry, locomotion, and the evolution of the anterior end: A lesson from sea urchins. *Evolution*, *48*, 1130–46.

Harnad, S. (1990). The symbol grounding problem. *Physica D: Nonlinear Phenomena, 42*, 335–46.

Hauk, O., Johnsrude, I., and Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron, 41*, 301–7.

Havas, D. A., Glenberg, A. M., Gutowski, K. A., Lucarelli, M. J., and Davidson, R. J. (2010). Cosmetic use of botulinum toxin-A affects processing of emotional language. *Psychological Science*, *21*, 895–900.

Havas, D. A., Glenberg, A. M., and Rinck, M. (2007). Emotion simulation during language comprehension. *Psychonomic Bulletin & Review, 14*, 436–41.

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,* B79–89.

Lakoff, G., and Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.

Landauer, T. K., and Dumais, S. T. (1997). A solution to Plato's problem: A latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review*, *104*, 211–40.

Louwerse, M. (2008). Embodied relations are encoded in language. *Psychonomic Bulletin & Review*, *15*, 838–44.

Louwerse, M., and Connell, L. (2011). A taste of words: Linguistic context and perceptual simulation predict the modality of words. *Cognitive Science*, *35*, 381–98.

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

MacIver, M. A. (2009). Neuroethology: From morphological computation to planning. In P. Robbins and M. Aydede (Eds.) *Cambridge handbook of situated cognition* (pp. 480–504). Cambridge: Cambridge University Press.

Mahon, B. Z., and 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.

Martin, A. (2007). The representation of object concepts in the brain. *Annual Review of Psychology, 58*, 25–45.

Masson, M., Bub, D., and Warren, C. (2008). Kicking calculators: Contribution of embodied representations to sentence comprehension. *Journal of Memory and Language*, *59*, 256–65.

Meteyard, L., Bahrami, B., and Vigliocco, G. (2007). Motion detection and motion words: Language affects low-level visual perception. *Psychological Science, 18*, 1007–13.

Paulin, M. G. (2005). Evolutionary origins and principles of distributed neural computation for state estimation and movement control in vertebrates. *Complexity*, *10*, 56–65.

Pickering, M. J., and Garrod, S. (2013). An integrated theory of language production and comprehension. *Behavioral and Brain Sciences, 36*(4), 329–47.

Pulvermüller, F. (1999). Words in the brain's language. *Behavioral and Brain Sciences, 22,* 253–79.

Richardson, D. C., and Matlock, T. (2007). The integration of figurative language and static depictions: An eye movement study of fictive motion. *Cognition, 102*, 129–38.

Rizzolatti, G., Sinigaglia, C., and Anderson, F. (2008). *Mirrors in the brain: How our minds share actions and emotions*. Oxford: Oxford University Press.

Santiago, J., Lupianez, J., Perez, E., and Fuenes, M. J. (2007). Time (also) flies from left to right. *Psychonomic Bulletin & Review, 14*, 512–16.

Searle, J. (1980). Minds, brains, and computers. *Behavioral and Brain Sciences*, *3*, 417–57.

Sell, A. J., and Kaschak, M. P. (2011). Processing time shifts affects the execution of motor responses. *Brain and Language, 117*, 39–44.

Stanfield, R. A., and Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science, 12*, 153–56.
Taylor, L. J., and Zwaan, R. A. (2008). Motor resonance and linguistic focus. *Quarterly Journal of Experimental Psychology, 61*, 896–904.
Tettamanti, M., Buccino, G., Saccuman, M. C., *et al.* (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience, 17*, 273–81.
Ulrich, R., Eikmeier, V., de la Vega, I., Rernandez, S. R., Alex-Ruf, S., and Maienborn, C. (2012). With the past behind and the future ahead: Back-to-front representation of past and future sentences. *Memory and Cognition*, *40*, 483–95.
Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space, and quantity. *Trends in Cognitive Science,* 7, 483–88.
Wolpert, D. M., Ghahramani, Z., and Flanagan, J. R. (2001). Perspectives and problems in motor learning. *Trends in Cognitive Sciences*, *5*, 487–94.
Zwaan, R. A., Madden, C. J., Yaxley, R. H., and Aveyard, M. E. (2004). Moving words: Dynamic mental representations in language comprehension. *Cognitive Science, 28,* 611–19.
Zwaan, R. A., Stanfield, R. A., and Yaxley, R. H. (2002). Language comprehenders mentally represent the shape of objects. *Psychological Science, 13,* 168–71.
Zwaan, R. A., and Taylor, L. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General, 135,* 1–11.