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Grounded Cognition: Past, Present, and Future

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Abstract

Thirty years ago, grounded cognition had roots in philosophy, perception, cognitive linguistics, psycholinguistics, cognitive psychology, and cognitive neuropsychology. During the next 20 years, grounded cognition continued developing in these areas, and it also took new forms in robotics, cognitive ecology, cognitive neuroscience, and developmental psychology. In the past 10 years, research on grounded cognition has grown rapidly, especially in cognitive neuroscience, social neuroscience, cognitive psychology, social psychology, and developmental psychology. Currently, grounded cognition appears to be achieving increased acceptance throughout cognitive science, shifting from relatively minor status to increasing importance. Nevertheless, researchers wonder whether grounded mechanisms lie at the heart of the cognitive system or are peripheral to classic symbolic mechanisms. Although grounded cognition is currently dominated by demonstration experiments in the absence of well-developed theories, the area is likely to become increasingly theory driven over the next 30 years. Another likely development is the increased incorporation of grounding mechanisms into cognitive architectures and into accounts of classic cognitive phenomena. As this incorporation occurs, much functionality of these architectures and phenomena is likely to remain, along with many original mechanisms. Future theories of grounded cognition are likely to be heavily influenced by both cognitive neuroscience and social neuroscience, and also by developmental science and robotics. Aspects from the three major perspectives in cognitive science—classic symbolic architectures, statistical/dynamical systems, and grounded cognition—will probably be integrated increasingly in future theories, each capturing indispensable aspects of intelligence.

Keywords: Architectures; Embodiment; Grounding; Imagery; Knowledge; Mental simulation; Situated cognition; Symbolic operations

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1. Introduction

According to classic theories, the core knowledge representations in cognition are amodal data structures processed independently of the brain's modal systems for perception, action, and introspection.[1] From this perspective, the core representations in cognition differ from representations in modal systems, function according to different principles, and reside in a modular semantic system (Tulving, 1983). Grounded cognition is often defined negatively as the view that classic theories are incorrect: The core knowledge representations in cognition are *not* amodal data structures that exist independently of the brain's modal systems. Instead—according to a positive definition of grounded cognition—the environment, situations, the body, and simulations in the brain's modal systems ground the central representations in cognition. From this perspective, the cognitive system utilizes the environment and the body as external informational structures that complement internal representations. In turn, internal representations have a situated character, implemented via simulations in the brain's modal systems, making them well suited for interfacing with external structures.

2. The past 30 years

Grounded cognition has a venerable history over two millennia, existing long before modern cognitive science. Prescientific accounts of the human mind, from ancient philosophers (e.g., Epicurus, 341–270BC/1987), to British empiricists (e.g., Berkeley, 1982; Hume, 1978; Locke, 1959), to 20th-century philosophers (e.g., Price, 1953; Russell, 1919), assumed that modal images represent knowledge, analogous to current views. Even nativists (e.g., Kant, 1965; Reid, 1969) frequently discussed modal images in knowledge (among other constructs).[2]

Around 30 years ago—peripheral to the amodal approaches that emerged from the Cognitive Revolution—grounded cognition took a variety of forms in cognitive science. In philosophy, Searle (1980) proposed the Chinese Room Problem as an example of how amodal representations in cognition are typically ungrounded. In cognitive linguistics, Lakoff and Johnson (1980) proposed conceptual metaphor theory, conjecturing that bodily experience grounds abstract concepts. In ecological optics, Gibson (1979) proposed that the environment plays important roles in supporting the internal processes underlying perception. In cognitive psychology, Paivio (1971), Shepard and Cooper (1982), and Kosslyn (1980) developed clever behavioral paradigms to demonstrate that perceptual representations implement mental imagery in higher cognition. In psycholinguistics, Bransford and Johnson (1973) and Clark and Marshall (1981) demonstrated that situations play central roles in establishing the semantics of sentences and texts, along with the pragmatics of common ground. In cognitive neuropsychology, Warrington and Shallice (1984) demonstrated that lesions in the brain's modal systems constitute one source of deficits in category knowledge, suggesting that modal systems play roles in representing knowledge. Although these lines of research captured significant interest in the cognitive science community, they had relatively little influence on the dominant amodal theories of the time.

Over the next 20 years, grounded cognition continued evolving, but again remained relatively peripheral. Philosophers continued to stress the seriousness of the grounding problem (e.g., Harnad, 1990). Cognitive linguists, such as Talmy (1983), Langacker (1987), and Fauconnier (1985), proposed cognitive grammars and mental spaces grounded in experience as accounts of language and thought. In cognitive ecology, Hutchins (1995) documented the distributed nature of cognition across the environment, situations, and agents. In robotics, Brooks (1991) and Kirsh (1991) advocated incorporating the environment and the body into a new generation of robots. In cognitive neuroscience, Kosslyn (1994) and Jeannerod (1995) demonstrated that mental imagery arises in the brain's modal systems for perception and action, corroborating earlier behavioral research on imagery. In developmental psychology, Thelen and Smith (1994) demonstrated that the environment, the body, and the motor system play central roles in the development of intelligence. In cognitive psychology, Barsalou (1993, 1999) proposed that knowledge is grounded in a compositional system of perceptual symbols.

The past 10 years have witnessed an explosion of research on grounded cognition. Not only has the salience of this work increased dramatically, it has increasingly been viewed as challenging dominant theories. One of the most significant areas has been cognitive neuroscience, where researchers such as Martin (2001, 2007), Pulvermüller (1999, 2005), and Thompson-Schill (2003) performed neuroimaging on tasks that engage memory, knowledge, language, and thought. Of interest was the general finding that the brain's modal systems become active as people perform these tasks, suggesting that higher cognition is grounded in modal systems. In social neuroscience, researchers such as Rizzolatti and Craighero (2004) and Decety and Grèzes (2006) found that as nonhuman primates and humans perceive social situations, they run simulations in their motor and affective systems to comprehend social action, generate empathy, and engage in other social processes. In cognitive psychology, many researchers, including Glenberg (1997), Zwaan (2004), Gibbs (2006), Hegarty (2004), W. Prinz (1997), Wilson (2002), Wilson and Knoblich (2005), Rubin (2006), and Barsalou (2008a), found that sensory-motor variables affect diverse tasks associated with perception, action, memory, knowledge, language, and thought, implicating the brain's modal systems throughout cognition. Similarly in social psychology, many researchers found that manipulating bodily states for the face, head, arms, and torso causally affects higher cognitive processes, such as evaluation, decision making, and attribution (Barsalou, Niedenthal, Barbey, & Ruppert, 2003; Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005). In developmental psychology, L. Smith (2005) (also L. Smith & Gasser, 2005) continued demonstrating that the environment and the body play central roles in the development of intelligence. In philosophy, researchers continued focusing on central roles of grounding in cognition (e.g., J. Prinz, 2002).

3. Current status

Empirical demonstrations of grounding across diverse areas and phenomena increase exponentially (e.g., Barsalou, 2008a; Gibbs, 2006; Pecher & Zwaan, 2005; Semin & Smith, 2008; de Vega, Glenberg, & Graesser, 2008). As a result of these accumulating demonstrations, there appears to be increasing awareness and acceptance that grounding is at least somewhat involved in higher cognition. There is also increased interest, however, in understanding the implications of these demonstrations for theory. One possibility is that grounding mechanisms play relatively peripheral, or even epiphenomenal, roles in higher cognition. Perhaps these mechanisms simply accompany the standard symbolic mechanisms in classic architectures, which causally determine processing. Alternatively, grounding mechanisms may play these causal roles themselves. The fact that manipulating grounding mechanisms in well-controlled laboratory experiments affects higher cognition suggests that these mechanisms play causal roles (Barsalou, 2008a, p. 632). Effects of transcranial magnetic stimulation on higher cognition further implicate the causal role of grounding mechanisms (e.g., Buccino et al., 2005; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005). Future research will undoubtedly focus increasingly on the causal roles of grounding mechanisms in cognition.

Another limitation of current work is the relative lack of formal and computational accounts. It is fair to say that current empirical research on grounded cognition heavily reflects demonstration experiments. As philosophers of science note, when a new area emerges, demonstration experiments dominate to justify the area's importance. Eventually, mechanistic theories develop that stimulate new generations of research, distinguish between mechanistic accounts, and elaborate mechanistic accounts further. Mechanistic accounts of grounded cognition have existed for some time and continue to emerge increasingly (e.g., Cangelosi & Riga, 2006; Farah & McClelland, 1991; Feldman, 2006; Pezzulo & Calvi, in press; Plaut, 2002; Wennekers, Garagnani, & Pulvermüller, 2006). Some preexisting systems have much potential for development as grounded theories (e.g., O'Reilly & Norman, 2002; Ullman, Vidal-Naquet, & Sali, 2002). In addition, various preformal architectures have potential for development as computational systems (e.g., Damasio, 1989; Simmons & Barsalou, 2003). In general, though, it is clear that much further theoretical development remains, and that such developments will move the area forward significantly.

Another question of much current interest is: What's amodal in the brain? One possibility entertained widely at the moment is a mixed account, with a classic symbolic engine implementing core cognitive operations, and grounding mechanisms being epiphenomenal, or simply serving to interface core operations with the world. Another flavor of this account is that, instead of classic symbolic mechanisms, a statistical engine implements core cognitive operations, again with grounding mechanisms being peripheral. Another position articulated frequently is that amodal symbols are central in certain special domains, such as number and space. In these domains, amodal representations may integrate and stand for information across modalities, although another possibility is that modal representations are linked directly with no amodal representations intervening. Finally, another mixed approach—originating in Paivio's (1971) Dual Code Theory—is that language and simulation work together to produce human cognition (e.g., Barsalou, Santos, Simmons, & Wilson, 2008; Louwerse & Jeuniaux, 2008).

Other central issues currently include how the brain implements symbolic operations and abstract concepts, phenomena that might be difficult to explain from the grounded perspective. One possibility is that amodal symbols are required to implement symbolic operations, such as predication, argument binding, conceptual combination, recursion, and so forth. Alternatively, grounded theories offer ways of explaining symbolic operations via simulation mechanisms (e.g., Barsalou, 1999, 2005, 2008b). As mentioned earlier, conceptual metaphor theory explains abstract concepts as grounded in embodiment (e.g., Gibbs, 1994; Lakoff & Johnson, 1980, 1999). Another compatible possibility is that abstract concepts are grounded in simulations of introspective experience and situations (e.g., Barsalou, 1999; Barsalou & Wiemer-Hastings, 2005).

Finally, within the area of grounded cognition itself, there is considerable speculation that grounding will lead to significant new discoveries in relations between perception, action, and cognition. Traditionally, integrating perception, action, and cognition has been difficult, reflecting the grounding problem (e.g., Harnad, 1990; Searle, 1980). If, however, cognition heavily utilizes mechanisms for perception and action, then grounded accounts have potential to unify perception, action, and cognition in the brain. There is also speculation that grounding will lead to significant new understandings about representation and knowledge, and also about the development of intelligence.

4. The next 30 years

One prediction is that cognitive science will increasingly witness the integration of three major perspectives—classic symbolic architectures, statistical/dynamical systems, and grounded cognition—with competition between them decreasing. Aspects of classic symbolic architectures will remain because of the central role that symbolic operations play in human intelligence (e.g., Barsalou, 1999, 2005, 2008b). These aspects, however, will be integrated with statistical/dynamical mechanisms and be grounded in the brain's modal systems. Specifically, the *functionality* of classic architectures will remain but be implemented in statistical/dynamical and grounding mechanisms, changing not only how we think about symbolic processing but also how we implement it in artificial intelligence. Each perspective offers important insights into how the brain works and is indispensable for a complete and powerful account.

Another prediction is that grounding will eventually become a standard aspect of theories and no longer be controversial. Specifically, the environment, situations, bodies, and simulations will become increasingly integrated into theories and play increasingly central roles in them. Furthermore, grounding is likely to play causal, not epiphenomenal, roles. Because grounding mechanisms such as simulation have the potential to implement symbolic operations and represent knowledge, they are likely to play roles in implementing the core functionality of classic symbolic architectures.

As research on grounded cognition evolves, computational and formal accounts of grounding are likely to develop increasingly. In parallel, empirical research will become less demonstrational and increasingly theory driven. Future experiments are likely to play central roles in developing mechanistic accounts of grounding and in discriminating between them.

Another prediction—perhaps wishful thinking—is that the integration of grounding mechanisms into existing research will be relatively painless. From this perspective, the functionality of classic empirical phenomena such as similarity, analogical reasoning, Bayesian inference, and so forth is likely to remain largely the same. What is likely to change is that additional levels of explanation associated with grounding develop, replacing the original amodal accounts of representation associated with these phenomena. A related prediction is that a similar evolution will occur for cognitive architectures. Much of the mechanistic structure and functionality of these architectures will remain, with grounding mechanisms replacing the corresponding amodal mechanisms.

To the extent that new grounded architectures develop, they are likely to heavily reflect influences from both cognitive neuroscience and social neuroscience. New architectures are also likely to incorporate mechanisms from existing computational accounts, to be heavily constrained by behavioral research, and to be influenced by developmental psychology. Rather than simply building an adult system, researchers will increasingly attempt to build infant systems that develop into fully intelligent systems (Smith, 2005; Smith & Gasser, 2005). Finally, to the extent that successful grounded architectures develop, they are likely to produce increasingly effective robots that provide good test beds for assessing these architectures (Barsalou, Breazeal, & Smith, 2007).

Notes

1. Introspection includes the internal perception of motivational states, affective states, goals, beliefs, cognitive operations, meta-cognition, and so forth.
2. Researchers often refer to the research reviewed here as ''embodied cognition.'' Although some of this research implicates the body as an important grounding mechanism, much other research implicates the modalities, the physical environment, and the social environment as important grounding mechanisms as well. Thus, referring to all this research as ''embodied'' cognition fails to capture the wide scope of grounding mechanisms, while simultaneously giving the mistaken impression that bodily states always determine the course of cognition. ''Grounded cognition'' captures the broad scope of grounding mechanisms, while not placing undue emphasis on the body.

References

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, & M. A. Conway (Eds.), *Theories of memory* (pp. 29–101). London: Lawrence Erlbaum Associates.

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

Barsalou, L. W. (2005). Abstraction as dynamic interpretation in perceptual symbol systems. In L. Gershkoff-Stowe & D. Rakison (Eds.), *Building object categories* (pp. 389–431). Carnegie Symposium Series. Mahwah, NJ: Erlbaum.

Barsalou, L. W. (2008a). Grounded cognition. *Annual Review of Psychology*, *59*, 617–645.

Barsalou, L. W. (2008b). Grounding symbolic operations in the brain's modal systems. In G. R. Semin & E. R. Smith (Eds.), *Embodied grounding: Social, cognitive, affective, and neuroscientific approaches* (pp. 9–42). New York: Cambridge.

Barsalou, L. W., Breazeal, C., & Smith, L. B. (2007). Cognition as coordinated non-cognition. *Cognitive Processing*, *8*, 79–91.

Barsalou, L. W., Niedenthal, P. M., Barbey, A., & Ruppert, J. (2003). Social embodiment. In B. Ross (Ed.), *The psychology of learning and motivation*, Vol. 43 (pp. 43–92). San Diego: Academic Press.

Barsalou, L. W., Santos, A., Simmons, W. K., & Wilson, C. D. (2008). Language and simulation in conceptual processing. In M. De Vega, A. M. Glenberg, & A. C. A. Graesser (Eds.), *Symbols, embodiment, and meaning* (pp. 245–283). Oxford, England: Oxford University Press.

Barsalou, L. W., & Wiemer-Hastings, K. (2005). Situating abstract concepts. In D. Pecher & R. Zwaan (Eds.), *Grounding cognition: The role of perception and action in memory, language, and thought* (pp. 129–163). New York: Cambridge.

Berkeley, G. (1982). *A treatise concerning the principles of human knowledge*. Indianapolis, IN: Hackett. (Original work published in 1710).

Bransford, J. D., & Johnson, M. K. (1973). Considerations of some problems of comprehension. In W. G. Chase (Ed.), *Visual information processing* (pp. 383–462). New York: Academic Press.

Brooks, R. A. (1991). Intelligence without representation. *Artificial Intelligence*, *47*, 139–159.

Buccino, G., Riggio, L., Melli, 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.

Cangelosi, A., & Riga, T. (2006). An embodied model for sensorimotor grounding and grounding transfer: Experiments with epigenetic robots. *Cognitive Science*, *30*, 673–689.

Clark, H. H., & Marshall, C. (1981). Definite reference and mutual knowledge. In A. Joshi, B. Webber, & I. Sag (Eds.), *Elements of discourse understanding* (pp. 10–63). New York: Cambridge.

Damasio, A. R. (1989). Time-locked multiregional retroactivation: A systems-level proposal for the neural substrates of recall and recognition. *Cognition*, *33*, 25–62.

Decety, J., & Grèzes, J. (2006). The power of simulation: Imagining one's own and other's behavior. *Brain Research*, *1079*, 4–14.

Epicurus (341-270BC). (1987). Sensation, imagination, and memory. In A. A. Long & D. N. Sedley (Eds.), *The Hellenistic philosophers*, Vol. 1 (pp. 72–101). New York: Cambridge.

Farah, M. J., & McClelland, J. L. (1991). A computational model of semantic memory impairment: Modality specificity and emergent category specificity. *Journal of Experimental Psychology: General*, *120*, 339–357.

Fauconnier, G. (1985). *Mental spaces*. Cambridge, MA: MIT Press.

Feldman, J. A. (2006). *From molecule to metaphor: A neural theory of language*. Cambridge, MA: MIT.

Gibbs Jr., R. W. (1994). *The poetics of mind: Figurative thought, language, and understanding*. New York: Cambridge University Press.

Gibbs Jr., R. W. (2006). *Embodiment and cognitive science*. New York: Cambridge University Press.

Gibson, J. J. (1979). *The ecological approach to visual perception*. New York: Houghton Mifflin.

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

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

Hegarty, M. (2004). Mechanical reasoning as mental simulation. *TRENDS in Cognitive Sciences*, *8*, 280–285.

Hume, D. (1978). *A treatise on human nature* (2nd ed.). Oxford, England: Oxford University Press. (Original work published in 1739).

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

Jeannerod, M. (1995). Mental imagery in the motor context. *Neuropsychologia*, *33*, 1419–1432.
Kant, E. (1965). *The critique of pure reason* (N. K. Smith, Trans). New York: St. Martin's Press. (Original work published in 1787).
Kirsh, D. (1991). Today the earwig, tomorrow man. *Artificial Intelligence*, *47*, 161–184.
Kosslyn, S. M. (1980). *Image and mind*. Cambridge, MA: Harvard University Press.
Kosslyn, S. M. (1994). *Image and brain*. Cambridge, MA: MIT Press.
Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.
Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to western thought*. New York: Basic Books.
Langacker, R. W. (1987). *Foundations of cognitive grammar: Vol. 1. Theoretical prerequisites*. Stanford, CA: Stanford University Press.
Locke, J. (1959). *An essay concerning human understanding* (1st ed., Vol. I and II). New York: Dover. (Original work published in 1690).
Louwerse, M. M., & Jeuniaux, P. (2008). Language comprehension is both embodied and symbolic. In M. de Vega, A. Glenberg, & A. C. Graesser (Eds.), *Symbols, embodiment, and meaning: A debate* (pp. 309–326). Oxford, England: Oxford University Press.
Martin, A. (2001). Functional neuroimaging of semantic memory. In R. Cabeza & A. Kingstone (Eds.), *Handbook of functional neuroimaging of cognition* (pp. 153–186). Cambridge, MA: MIT Press.
Martin, A. (2007). The representation of object concepts in the brain. *Annual Review of Psychology*, *58*, 25–45.
Niedenthal, P. M., Barsalou, L. W., Winkielman, P., Krauth-Gruber, S., & Ric, F. (2005). Embodiment in attitudes, social perception, and emotion. *Personality and Social Psychology Review*, *9*, 184–211.
O'Reilly, R. C., & Norman, K. A. (2002). Hippocampal and neocortical contributions to memory: Advances in the complementary learning systems framework. *Trends in Cognitive Sciences*, *6*, 505–510.
Paivio, A. (1971). *Imagery and verbal processes*. New York: Holt, Rinehart & Winston.
Pecher, D., & Zwaan, R. (Eds.) (2005). *Grounding cognition: The role of perception and action in memory, language, and thought*. New York: Cambridge University Press.
Pezzulo, G., & Calvi, G. (in press). Computational explorations of perceptual symbol system theory. *New Ideas in Psychology*.
Plaut, D. C. (2002). Graded modality-specific specialization in semantics: A computational account of optic aphasia. *Cognitive Neuropsychology*, *19*, 603–639.
Price, H. H. (1953). *Thinking and experience*. London: Hutchinson's Universal Library.
Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*, *9*, 129–154.
Prinz, J. (2002). *Furnishing the mind: Concepts and their perceptual basis*. Cambridge, MA: MIT.
Pulvermüller, F. (1999). Words in the brain's language. *Behavioral and Brain Sciences*, *22*, 253–336.
Pulvermüller, F. (2005). Brain mechanisms linking language and action. *Nature Reviews Neuroscience*, *6*, 576–582.
Pulvermüller, F., Hauk, O., Nikulin, V. V., & Ilmoniemi, R. J. (2005). Functional links between motor and language systems. *European Journal of Neuroscience*, *21*, 793–797.
Reid, T. (1969). *Essays on the intellectual powers of man*. Cambridge, MA: MIT Press. (Original work published in 1785).
Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience*, *27*, 169–192.
Rubin, D. C. (2006). The basic-systems model of episodic memory. *Perspectives on Psychological Science*, *1*, 277–311.
Russell, B. (1919). On propositions: What they are and how they mean. *Aristotelean Society Supplementary*, *2*, 1–43. (Reprinted in Slater, J. G. (Ed.) (1986). *The collected papers of Bertrand Russell, Volume 8: The philosophy of logical atomism and other essays, 1914-19* (pp. 276–306). London: George Allen & Unwin.)
Searle, J. R. (1980). Minds, brains, and programs. *Behavioral and Brain Sciences*, *3*, 417–424.
Semin, G. R., & Smith, E. R. (Eds.) (2008). *Embodied grounding: Social, cognitive, affective, and neuroscientific approaches*. New York: Cambridge University Press.

Shepard, R. N., & Cooper, L. A. (1982). *Mental images and their transformations*. New York: Cambridge University Press.

Simmons, W. K., & Barsalou, L. W. (2003). The similarity-in-topography principle: Reconciling theories of conceptual deficits. *Cognitive Neuropsychology*, *20*, 451–486.

Smith, L. B. (2005). Cognition as a dynamic system: Principles from embodiment. *Developmental Review*, *25*, 278–298.

Smith, L. B., & Gasser, M. (2005). The development of embodied cognition: Six lessons from babies. *Artificial Life*, *11*, 13–30.

Talmy, L. (1983). How language structures space. In H. Pick & L. Acredelo (Eds.), *Spatial orientation: Theory, research, and application* (pp. 225–282). New York: Plenum Press.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.

Thompson-Schill, S. L. (2003). Neuroimaging studies of semantic memory: inferring ''how'' from ''where.'' *Neurosychologia*, *41*, 280–292.

Tulving, E. (1983). *Elements of episodic memory*. New York: Oxford University Press.

Ullman, S., Vidal-Naquet, M., & Sali, E. (2002). Visual features of intermediate complexity and their use in classification. *Nature Neuroscience*, *5*, 1–6.

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

Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain*, *107*, 829–854.

Wennekers, T., Garagnani, M., & Pulvermüller, F. (2006). Language models based on Hebbian cell assemblies. *Journal of Physiology – Paris*, *100*, 16–30.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*, 625–636.

Wilson, M., & Knoblich, G. (2005). The case for motor involvement in perceiving conspsecifics. *Psychological Bulletin*, *131*, 460–473.

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). York: Academic Press.