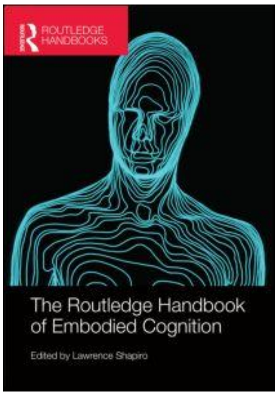

The Routledge Handbook of Embodied Cognition

Lawrence Shapiro

Gesture in Reasoning

Publication details
https://www.routledgehandbooks.com/doi/10.4324/9781315775845.ch15
Martha W. Alibali, Rebecca Boncoddo, Autumn B. Hostetter
Published online on: 01 May 2014

15
GESTURE IN REASONING

An embodied perspective

Martha W. Alibali, Rebecca Boncoddo, and Autumn B. Hostetter

Introduction

Theories of embodied cognition claim that cognitive processes are rooted in interactions of the human body with the physical world. The core idea is that cognition depends on the specifics of the body and its actual or possible actions in the world. This embodied perspective is the basis for a diverse set of theoretical positions and specific claims regarding perception, cognition, and language (Anderson, 2003; Shapiro, 2011; Wilson, 2002). In this chapter, we take an embodied perspective on *reasoning*, which we define as cognitive processing in service of inference, judgment, or solving problems. We review research relevant to two central claims of the embodied cognition perspective: (1) reasoning is based in perception and action; and (2) reasoning is grounded in the physical environment.

A growing body of research shows that actions – including both physical actions that people perform and simulated actions that people imagine – can affect reasoning and problem solving. In this chapter, we focus on one special type of action – gesture. Gestures are movements of the hands and body that are integrally connected with thinking, and often, with speaking.

Many past studies have considered speakers' gestures as evidence that the knowledge expressed in those gestures is "embodied." Indeed, a recent theoretical account, the Gesture as Simulated Action (GSA) framework (Hostetter and Alibali, 2008), holds that gestures derive from simulated actions. This view builds on the idea that mental simulations of actions and perceptual states activate the same neural areas that are used in actual actions and perception. According to the GSA framework, this activation is not always completely inhibited during speaking, and it can be expressed in gestures.

From this perspective, then, gestures yield evidence for the embodiment of cognition because they derive from simulated actions and perceptions. At the same time, gestures are also actions. As such, gestures may directly affect thought, in many of the same ways that action can.

In this chapter, we focus on gesture and its role in an embodied account of reasoning. We first address the distinction between action and gesture. We then consider three broad claims regarding gesture and reasoning: (1) gesture production manifests embodied processes in reasoning; (2) gesture production plays a causal role in reasoning by raising activation on perceptual-motor information; and (3) gesture communicates information that affects listeners' reasoning.

What are gestures?

Actions are movements of parts of the body. As such, actions involve an interaction between an individual and the physical environment. In many cases, actions involve manipulating or moving objects. *Gestures* are a special form of action that typically do not involve acting on the environment or manipulating objects. Instead, gestures involve moving a part of the body (often the hands or arms) in order to express an idea or meaning. Gestures are not produced in order to act upon the world; instead, they are produced as part of the cognitive processes that underlie thinking and speaking.

The distinction between gestures and other actions is not always clear-cut. Gestures typically represent things without utilizing objects; however, in some cases people use objects to gesture (e.g. pointers). Additionally, people may hold up or manipulate objects in the course of speaking or thinking in ways that seem to be gestures. Some researchers consider only movements produced along with speech to be gestures (e.g. Goldin-Meadow, 2003, p. 8), while others take a broader view, including movements produced when thinking in silence (e.g. Chu and Kita, 2011). Our focus in this chapter is on gestures as a form of action, so we take a broad perspective. We consider gestures to be actions that are produced as part of the cognitive processes involved in speaking or thinking.

Several classification systems for gestures have been proposed (e.g. McNeill, 1992). Our focus in this chapter is primarily on *representational* gestures, which are gestures that depict some aspect of their meaning via hand shape or motion (e.g. moving the hand in a circle to represent *spin*). We also consider *pointing* gestures, a subtype of representational gestures, which indicate objects or locations. These types of gestures can be distinguished from *beat* gestures, which are motorically simple, rhythmic movements, akin to beating time, and *interactive* gestures, which are used to regulate turn-taking and other aspects of interaction.

There are a number of contemporary theories about the cognitive processes that give rise to gestures (e.g. Kita and Özyürek, 2003; McNeill, 2005). One perspective, the GSA framework (Hostetter and Alibali, 2008), builds on an embodied perspective on language and cognitive processing, and makes explicit ties to action. Simply stated, the GSA framework proposes that gestures derive from simulated actions or perceptual states, which people utilize when thinking or when producing or comprehending language. These simulated actions and perceptual states activate corresponding motor and premotor areas of the brain (e.g. Hauk, Johnsrude, and Pulvermüller, 2004). When activation in these areas exceeds a critical threshold, people may produce overt movements, which we recognize as representational gestures.

The GSA framework builds on research establishing the role of action simulations in language comprehension (see Fischer and Zwaan, 2008, for review). For example, Glenberg and Kaschak (2002) studied comprehension of sentences that implied movement either towards or away from the body. Comprehension was affected by the direction of action required to make a response – compatible actions facilitated comprehension, and incompatible actions inhibited comprehension. Importantly, these findings held true both for sentences about literal movements (e.g. close the drawer) and sentences that implied movement figuratively (e.g. tell a story). These findings suggest that simulations of action are involved in language *comprehension*. The GSA framework holds that such simulations are also involved in language *production*, and that these simulations give rise to gestures.

Hostetter and Alibali (2010) tested the claim that gestures arise from highly activated simulations of action. In a series of experiments, they found that participants produced more gestures when describing information they acquired through physical actions compared with information they acquired visually. This evidence supports the central claim of the GSA framework, namely that gestures arise when speakers strongly simulate actions.

According to the GSA framework, gestures are particularly likely to occur along with speech, because the combined activation from speech production and mental simulation is likely to exceed the speaker's gesture threshold. However, producing speech is not necessary for a gesture to occur. In some cases, activation on action simulations can exceed the gesture threshold, even without the extra "boost" in activation provided by speech production. For example, when performing mental rotation tasks, many participants spontaneously produce gestures, even when they do not speak aloud (Chu and Kita, 2011). Similarly, when given a configuration of gears and asked to predict the movement of a specific gear without talking aloud, many participants spontaneously produce gestures depicting gear movements (Alibali, Spencer, Knox, and Kita, 2011, experiment 2). These studies suggest that people gesture when they engage in cognitive processing that involves highly activated simulations of actions or perceptual states, even if they are not also producing speech.

Gesture production manifests embodied processes in reasoning

The embodied cognition perspective holds that thought is based in perception and action. If gestures do, in fact, derive from simulated actions and perceptual states, as claimed by the GSA framework, then gestures provide prima facie evidence for this claim. When speakers express ideas that they mentally represent in simulations of actions and perceptual states, they naturally produce gestures, and these gestures manifest the embodied nature of those ideas.

Gestures that manifest simulated actions and perceptions commonly occur with the verbalizations that people produce during reasoning and problem-solving tasks. Not surprisingly, people often produce gestures when talking about *bodily actions* that they have performed (or could perform). For example, Cook and Tanenhaus (2009) studied the gestures participants produced when explaining their solutions to the Tower of Hanoi puzzle, which they had solved either using real disks and pegs or on a computer. Participants in both conditions described moving the disks in speech and gestures, but participants in the real-objects condition produced a greater proportion of gestures that used grasping hand shapes (like the actions they produced when actually moving the disks) than participants in the computer condition. Thus, people's gestures were aligned with the actual actions they had produced earlier in the experiment, which they presumably called to mind when explaining their solutions.

People also produce gestures when they engage in other forms of reasoning that involve simulated actions and perceptions, such as when they reason about physical forces (Roth, 2002) or when they form or manipulate mental images of objects or scenes that are not physically present (Chu and Kita, 2008; McNeill *et al.*, 2001). For example, Singer, Radinsky, and Goldman (2008) described the gestures children in a science class produced when discussing data about earthquakes and volcanoes. The children frequently produced representational gestures depicting the movements of tectonic plates, including rift, subduction, and buckling.

Perhaps most surprising is that people also use representational gestures when reasoning about *abstract ideas*. Several accounts of human cognition are compatible with the idea that simulations of actions and perceptual states are activated when thinking about abstract concepts (e.g. Barsalou, Simmons, Barbey, and Wilson, 2003; Glenberg *et al.*, 2008; Lakoff and Johnson, 1980). Lakoff and Johnson (1980) argued that many abstract concepts are understood in terms of metaphors that are based in the body or in human experience. These metaphors are sometimes manifested in the gestures that people produce when speaking or reasoning about abstract concepts. For example, one conceptual metaphor that applies in early mathematics is ARITHMETIC IS COLLECTING OBJECTS (Lakoff and Núñez, 2001), and this metaphor has been observed in gestures.

Marghetis, Bergen, and Núñez (2012) describe a student who says, "Because you add the same numbers" while producing a gesture in which she brings her hands, in grasping hand shapes, together in front of her body, representing gathering two collections or masses. Thus, evidence from gestures suggests that adding abstract entities, such as numbers, may involve a mental simulation of the physical action of collecting objects. Even abstract notions, such as mathematical concepts, are rooted in bodily actions.

Thus far, we have focused on gestures that display elements of people's mental simulations of actions and perceptual states by virtue of their form (hand shape or motion trajectory). However, not all gestures depict semantic content in this way; instead, some gestures express information by *pointing*. Pointing gestures index objects and locations in the physical world, and they have meaning by virtue of this indexing function (Glenberg and Robertson, 2000). A pointing gesture may directly refer to the object or location that it indicates (e.g. pointing to a cup to refer to that cup), or it can refer indirectly to a related or perceptually similar object (e.g. pointing to a cup on one's desk to refer to a cup at home) (Butcher, Mylander, and Goldin-Meadow, 1991). Pointing gestures can even refer metaphorically to abstract ideas by indicating "places" for those ideas (e.g. gesturing to one side to indicate the "pros" of a decision, and to the other side to indicate the "cons"). Thus, pointing gestures manifest another of the core claims of many theories of embodied cognition, namely, the notion that cognition is tied to the environment. Pointing gestures suggest that speakers utilize the environment as "part" of their cognitive system, by indexing present objects and locations, as well as non-present objects and locations, and even non-tangible ideas.

Thus, there are multiple ways in which gesture manifests embodied processes in human reasoning (see Alibali and Nathan, 2012, for further discussion). First, representational gestures display elements of mental simulations of actions and perceptual states. Second, some representational gestures reveal body-based and experiential metaphors that are associated with, and may underpin, certain abstract concepts. Finally, pointing gestures index words and ideas to the physical world. Thus, gestures suggest that cognition is both rooted in perception and action, and grounded in the physical environment.

Gesture production plays a causal role in reasoning

We have argued that gestures *reflect* thoughts that are grounded in sensory and motor processes – thus, gestures manifest embodied thinking. However, gestures may also do more. In this section, we present evidence that producing gestures can *affect* thought by increasing activation on perceptual and motor information.

Several studies have shown that *actions* can facilitate problem solving when they embody a problem's solution (e.g. Catrambone, Craig, and Nersessian, 2006). For example, Thomas and Lleras (2007) asked participants to solve Duncker's (1945) radiation problem, in which a doctor tries to destroy a tumor with a ray. If the ray is directed at the tumor with enough intensity to destroy it, it will also destroy the healthy tissue it passes through. At lesser intensities, the ray can safely pass through healthy tissue, but will not affect the tumor. The solution is to split the ray into multiple, less intense rays that will converge on the tumor. Participants worked on the radiation problem and took frequent breaks to do a seemingly unrelated eye-tracking task, in which they directed their eyes to a digit among an array of letters. In the critical condition, the location of the digits required that participants move their eyes repeatedly from the periphery of the screen to the center, mirroring the rays converging on the center from different locations. Participants who produced these seemingly unrelated eye movements were more likely to solve the radiation problem than participants who produced other eye movement patterns.

The effect of action is not limited to eye movements. Thomas and Lleras (2009) asked participants to solve Maier's (1931) two-string problem, which requires figuring out how to tie together two strings that are hanging from the ceiling at a far enough distance that participants cannot reach one while holding the other. The solution is to tie a pair of pliers that is available in the room to one string so that it will swing like a pendulum. Participants who took problem-solving breaks in which they engaged in arm-swinging "exercises" were more likely to solve the problem than were participants who engaged in stretching exercises that did not embody the problem's solution. Moreover, this effect held even for participants who were not aware that there was a connection between their movements and the solution.

These studies suggest that *actions* affect problem solving, but what about gestures? As discussed above, gestures are a special kind of action produced as part of the cognitive processes involved in speaking or thinking. In contrast to the arm-swinging movements produced by participants in Thomas and Lleras's (2009) study, gestures manifest specific ideas that people have in mind. According to the GSA framework, speakers produce gestures because they mentally simulate actions or perceptual states, and gestures represent salient or highly activated elements of those simulations.

Recent work suggests that, not only do gestures manifest elements of peoples' mental simulations, they can also affect those simulations, and thereby influence memory and problem solving (Cook, Yip, and Goldin-Meadow, 2010; Wesp, Hess, Keutmann, and Wheaton, 2001). The available data suggest that producing gestures raises activation on perceptual and motor elements of people's mental simulations, and highlights these elements as relevant and important for further cognitive processing (see Alibali and Kita, 2010; Goldin-Meadow and Beilock, 2010, for discussion).

In support of this view, when people gesture about a task or scene, they are especially likely to focus on perceptual elements of that task or scene. For example, Alibali and Kita (2010) asked children to explain their solutions to Piagetian conservation problems, with gesture either allowed or prohibited. Children were more likely to describe perceptually present information (e.g. perceptual features of the task objects, such as height, width, or length) when they gestured. When they did not gesture, children were more likely to describe how the problem looked previously or how it might look in the future, rather than how it looked at that moment. Thus, gestures appear to ground speakers' thinking and speaking in the perceptually present environment.

People can also use gestures to *generate* relational or action-based information that is not present in the problem at hand. Boncoddo, Dixon, and Kelly (2010) asked preschool children to solve gear-system problems, in which they had to determine which direction a final gear would turn, given information about how an initial gear turned. Children often traced the alternating sequence of gears in gestures as they attempted to solve the problems. Moreover, the more children traced the sequence, the more likely they were to discover the new idea that adjacent gears turn in alternating directions. Note that the alternating movements were not actually present in the display – instead, children generated the notion of alternation in their gestures. Thus, gestures introduced new information into children's reasoning.

Gestures can also affect reasoning, even when problems involve no visual display at all. In one study, college students were asked to imagine lines of varying numbers of gears, and to predict the direction of movement of the final gear, given the movement of the initial gear. Participants talked out loud as they solved the problems, and for some participants, gesture was prohibited. Participants who were allowed to gesture were *less likely* to discover that odd-numbered gears turn in the same direction as the initial gear and even-numbered gears turn in the opposite direction (the *parity* rule) than were participants who were prevented from gesturing. Instead, participants who were allowed to gesture tended to simulate the actions of each gear in order to predict the movement of the final gear (Alibali *et al.*, 2011, experiment 1). Thus, in this task, gestures highlighted perceptual and motor aspects of the task, even though those aspects were not perceptually present in the environment. Further, for this task, focusing on perceptual and motor information actually hindered performance, as it prevented participants from generating the highly efficient parity rule. Whether gesture helps or hinders seems to depend on whether perceptual and motor information is integral to the problem's solution.

This point is echoed in a recent study involving variations of the Tower of Hanoi puzzle (Beilock and Goldin-Meadow, 2010). When participants gestured about a version of the problem that had certain affordances (i.e. the smallest disk was the lightest), it impaired their ability to solve a version of the problem with different affordances (i.e. the smallest disk was the heaviest). Importantly, it was not simply talking about the problem or interacting with the initial version of the problem that impaired problem solving; on the contrary, only when speakers described their solution, and gestured while doing so, did they have difficulty solving the problem when the affordances changed. These findings suggest that gesturing about a particular simulation makes certain details of that simulation particularly salient in the speaker's mind. When the perceptual and motor details of that simulation are irrelevant to the problem, highlighting those details in gesture can be detrimental to problem solving.

In sum, there is considerable evidence to suggest that producing gestures highlights perceptual and motor information, both in the environment and in people's mental representations of tasks or scenes. As a result, when people produce gestures, they are more likely to incorporate perceptual and motor information into their reasoning.

Gesture communicates information that affects listeners' reasoning

Thus far, we have focused on gestures from the perspective of the individual who produces them. We have considered what gestures reveal about the cognitive processes of the gesturer, and we have considered the role of gesture in shaping those cognitive processes. In this section, we consider the other side of the interactional "coin" – that is, we consider speakers' gestures from the perspective of the listener (or observer). We argue that gesture may affect *listeners'* cognitive processing in two main ways. First, speakers' gestures may help listeners to *grasp speakers' referential intentions*, by indexing their utterances to objects or locations in the physical and socially shared environment. Second, speakers' gestures can help listeners to grasp *speakers' semantic intentions*, by helping them to simulate the actions and perceptual states that speakers have in mind.

As discussed above, pointing gestures communicate because they index words and phrases to objects and locations in the physical world (Glenberg and Robertson, 2000). Pointing gestures help listeners to make reference, especially when speech is ambiguous or degraded (Thompson and Massaro, 1994). From an embodied perspective, this phenomenon suggests that speakers' pointing gestures help listeners to index the referents that speakers intend. Thus, in communicative settings, pointing gestures affect listeners' reasoning because they help listeners grasp speakers' referential intentions.

Representational gestures also influence listeners' comprehension. There are at least two possible pathways by which this could occur. First, observing a speaker's representational gestures might guide listeners in constructing corresponding action simulations in their own minds (Alibali and Hostetter, 2011). When people observe others' actions, motor and premotor areas of their brains are activated in corresponding ways (Jeannerod, 2001; Rizzolatti, Fogassi, and Gallese, 2001; Wheaton, Thompson, Syngeniotis, Abbott, and Puce, 2004). Put simply, "our motor system simulates under threshold the observed action in a strictly congruent fashion" (Fadiga, Craighero, and Olivier, 2005, p. 213). Because gestures are a form of action, the same principles presumably apply in observing gestures. If gestures manifest simulated actions and perceptual states, then observing gestures may guide listeners to generate corresponding simulations in their own minds. In this way, speakers' representational gestures may help listeners to comprehend speakers' semantic intentions.

Second, observing speaker's gestures may encourage listeners to produce corresponding gestures themselves. That is, viewing a speaker's gestures may elicit overt mimicry of those gestures, and those gestures may in turn affect reasoning. A similar mechanism has been proposed for understanding facial expressions of emotion (the Simulation of Smiles model; Niedenthal, Mermillod, Maringer, and Hess, 2010). According to this model, both mimicry and simulation contribute to perceivers' understanding of different types of smiles. In a parallel fashion, we suggest that both overt gestural mimicry and covert simulation of corresponding actions contribute to listeners' comprehension of speakers' gestures.

Do listeners overtly mimic speakers' gestures, either in silence during the speaker's turn, or in their own subsequent turns? Indeed, such mimicry does occur. For example, children who received a math lesson in which the instructor gestured were themselves more likely to gesture when explaining math problems than children who received a similar lesson in which the instructor did not gesture (Cook and Goldin-Meadow, 2006). Moreover, children's gestures tended to reproduce the form of the instructor's gestures – thus, children mimicked the instructor's gestures.

Gestural mimicry is also evident in other discourse contexts, including conversation and narrative (Kimbara, 2006; Lakoff and Núñez, 2001). Moreover, people produce similar gestures more frequently when they can see one another than when they cannot (Holler and Wilkin, 2011; Kimbara, 2008) – suggesting that gestural mimicry is purposeful, and not simply due to people using similar gestures when they talk about similar things. Holler and Wilkin (2011) argue that gestural mimicry fosters shared understanding between participants in dialogue, in some cases by presenting semantic information that aligns with what the other had expressed on a previous turn, and at other times by displaying "acceptance" or comprehension of the other's communication.

However, despite evidence that gesture mimicry plays an important role in establishing shared understanding, overt mimicry of gestures seems unusual, rather than common. It is indeed rare to see listeners gesture when others are speaking; therefore, it seems likely that most of gesture's contribution to comprehension comes from gesture guiding covert action simulations, or facilitating reference via indexing.

In sum, there are multiple reasons why speakers' gestures may influence listeners' comprehension, and consequently their reasoning (Hostetter, 2011). First, speakers' gestures help listeners to index speakers' utterances to the physical environment. Second, speakers' gestures help listeners to construct simulations that align with those of the speakers. They may do so via two different pathways – by encouraging overt mimicry of gestural actions, or by guiding construction of appropriate simulations.

Conclusion

In this chapter, we have provided evidence for three broad claims regarding gesture and reasoning. First, we argued that gestures manifest embodied processes in reasoning. In line with the GSA framework, we argued that *representational gestures* derive from mental simulations of actions and perceptual states. When speakers express ideas based in simulations of actions and perceptual states, they often produce gestures, and those gestures manifest the embodied nature of those ideas. Further, we argued that *pointing gestures* index objects and locations in the physical world. As such, pointing gestures provide evidence for the claim that cognition is grounded in the physical environment.

Second, we presented evidence that gesture plays a causal role in reasoning, and that it does so by highlighting perceptual and motor information, both in the environment and in people's mental simulations of tasks or scenes. We argued that gestures raise activation on perceptual and motor information, and therefore, when people produce gestures, they are more likely to incorporate such information into their reasoning and problem solving.

Finally, we argued that speakers' gestures affect listeners' reasoning. Speakers' gestures guide listeners' indexing of speakers' utterances to the physical environment. In addition, speakers' gestures may help listeners to construct simulations that align with speakers' simulations. This may occur via listeners' direct mimicry of speakers' gestures, or by listeners using information expressed in speakers' gestures to guide and constrain their mental simulations.

In sum, gestures offer researchers a valuable window on the embodied cognitive processes involved in reasoning. Moreover, as a form of action, gestures play a functional role in those processes, as well. It is becoming increasingly clear that gestures are more than simple "hand waving." As such, a deeper understanding of how and why people gesture is critical for scientific progress in understanding human reasoning.

References

Alibali, M. W., and Hostetter, A. B. (2011). Mimicry and simulation in gesture comprehension. *Behavioral and Brain Sciences*, *33*, 433–34. (Commentary on Niedenthal, Maringer, Mermillod, and Hess, 2010.)

Alibali, M. W., and Kita, S. (2010). Gesture highlights perceptually present information for speakers. *Gesture*, *10*(1), 3–28.

Alibali, M. W., and Nathan, M. J. (2012). Embodiment in mathematics teaching and learning: Evidence from students' and teachers' gestures. *Journal of the Learning Sciences*, *21*(2), 247–86.

Alibali, M. W., Spencer, R. C., Knox, L., and Kita, S. (2011). Spontaneous gestures influence strategy choices in problem solving. *Psychological Science*, *22*(9), 1138–44.

Anderson, M. L. (2003). Embodied cognition: A field guide. *Artificial Intelligence*, *149*(1), 91–130.

Barsalou, L. W., Simmons, W. K., Barbey, A. K., and Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences*, *7*(2), 84–91.

Beilock, S. L., and Goldin-Meadow, S. (2010). Gesture changes thought by grounding it in action. *Psychological Science*, *21*(11), 1605–10.

Boncoddo, R., Dixon, J. A., and Kelley, E. (2010). The emergence of a novel representation from action: Evidence from preschoolers. *Developmental Science*, *13*(2), 370–77.

Butcher, C., Mylander, C., and Goldin-Meadow, S. (1991). Displaced communication in a self-styled gesture system: Pointing at the nonpresent. *Cognitive Development*, *6*, 315–42.

Catrambone, R., Craig, D. L., and Nersessian, N. J. (2006). The role of perceptually represented structure in analogical problem solving. *Memory and Cognition*, *34*(5), 1126–32.

Chu, M., and Kita, S. (2008). Spontaneous gestures during mental rotation tasks: Insights into the microdevelopment of the motor strategy. *Journal of Experimental Psychology: General*, *137*(4), 706–23.

——(2011). The nature of gestures' beneficial role in spatial problem solving. *Journal of Experimental Psychology: General*, *140*(1), 102–16.

Cook, S. W., and Goldin-Meadow, S. (2006). The role of gesture in learning: Do children use their hands to change their minds? *Journal of Cognition and Development*, *7*, 211–32.

Cook, S. W., and Tanenhaus, M. K. (2009). Embodied communication: Speakers' gestures affect listeners' actions. *Cognition*, *113*(1), 98–104.

Cook, S. W., Yip, T. K., and Goldin-Meadow, S. (2010). Gesturing makes memories that last. *Journal of Memory and Language*, *63*(4), 465–75.

Duncker, K. (1945). On problem solving (L. S. Lees, Trans.) (Special issue). *Psychological Monographs*, *58*(270).

Fadiga, L., Craighero, L., and Olivier, E. (2005). Human motor cortex excitability during the perception of others' action. *Current Opinion in Neurobiology*, *15*(2), 213–18.

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*(6), 825–50.

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*(6), 905–19.

Goldin-Meadow, S. (2003). *Hearing gesture: How our hands help us think*. Cambridge, MA: Harvard University Press.

Goldin-Meadow, S., and Beilock, S. L. (2010). Action's influence on thought: The case of gesture. *Perspectives on Psychological Science*, *5*(6), 664–74.

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

Holler, J., and Wilkin, K. (2011). Co-speech gesture mimicry in the process of collaborative referring during face-to-face dialogue. *Journal of Nonverbal Behavior*, *35*(2), 133–53.

Hostetter, A. B. (2011). When do gestures communicate? A meta-analysis. *Psychological Bulletin*, *137*(2), 297–315.

Hostetter, A. B., and Alibali, M. W. (2008). Visible embodiment: Gestures as simulated action. *Psychonomic Bulletin & Review*, *15*(3), 495–514.

——(2010). Language, gesture, action! A test of the Gesture as Simulated Action framework. *Journal of Memory and Language*, *63*, 245–57.

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage*, *14*, S103–9.

Kimbara, I. (2006). On gestural mimicry. *Gesture*, *6*(1), 39–61.

——(2008). Gesture form convergence in joint description. *Journal of Nonverbal Behavior*, *32*(2), 123–31.

Kita, S., and Özyürek, A. (2003). What does cross-linguistic variation in semantic coordination of speech and gesture reveal? Evidence for an interface representation of spatial thinking and speaking. *Journal of Memory and Language*, *48*, 16–32.

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

Lakoff, G., and Núñez, R. (2001). *Where mathematics comes from: How the embodied mind brings mathematics into being*. New York: Basic Books.

Maier, N. R. F. (1931). Reasoning in humans, II: The solution of a problem and its appearance in consciousness. *Journal of Comparative Psychology*, *12*, 181–94.

Marghetis, T., Bergen, B., and Núñez, R. (2012). Metaphorical conceptualization of arithmetic: Evidence in gesture of the flexible deployment of complementary construals of abstract arithmetic. Paper presented at the Fourth Annual Meeting of the UK Cognitive Linguistics Association, London, July.

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought*. Chicago: University of Chicago Press.

——(2005). *Gesture and thought*. Chicago: University of Chicago Press.

McNeill, D., Quek, F., McCullough, K. E., Duncan, S., Furuyama, N., Bryll, R., *et al.* (2001). Catchments, prosody, and discourse. *Gesture*, *1*(1), 9–33.

Niedenthal, P. M., Mermillod, M., Maringer, M., and Hess, U. (2010). The Simulation of Smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *Behavioral and Brain Sciences*, *33*, 417–80.

Rizzolatti, G., Fogassi, L., and Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, *2*, 661–70.

Roth, W. M. (2002). From action to discourse: The bridging function of gestures. *Cognitive Systems Research*, *3*, 535–54.

Shapiro, L. (2011). *Embodied cognition*. New York, NY: Routledge.

Singer, M. A., Radinsky, J., and Goldman, S. R. (2008). The role of gesture in meaning construction. *Discourse Processes*, *45*, 365–86.

Thomas, L. E., and Lleras, A. (2007). Moving eyes and moving thought: On the spatial compatibility between eye movements and cognition. *Psychonomic Bulletin & Review*, *14*(4), 663–68.

——(2009). Swinging into thought: Directed movement guides insight in problem solving. *Psychonomic Bulletin & Review*, *16*(4), 719–23.

Thompson, L. A., and Massaro, D. W. (1994). Children's integration of speech and pointing gestures in comprehension. *Journal of Experimental Child Psychology*, *57*, 327–54.

Wesp, R., Hess, J., Keutmann, D., and Wheaton, K. (2001). Gestures maintain spatial imagery. *American Journal of Psychology*, *114*, 591–600.

Wheaton, K. J., Thompson, J. C., Syngeniotis, A., Abbott, D. F., and Puce, A. (2004). Viewing the motion of human body parts activates different regions of premotor, temporal, and parietal cortex. *NeuroImage*, *22*(1), 277–88.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*, 625–36.