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Gesture in Thought

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Abstract and Keywords

The spontaneous gestures that speakers produce when they talk about a task reflect aspects of the speakers' knowledge about that task, aspects that are often not found in the speech that accompanies the gestures. But gesture can go beyond reflecting a speaker's current knowledge—it frequently presages the next steps the speaker will take in acquiring new knowledge, suggesting that gesture may play a role in cognitive change. To investigate this hypothesis, we explore the functions gesture serves with respect to both communication (the effects gesture has on listeners) and cognition (the effects gesture has on speakers themselves). We also explore the mechanisms that underlie the production of gesture, and we provide evidence that gesture has roots in speech, visuospatial thinking, and action. Gesturing is not merely hand waving, nor is it merely a window into the mind. It can affect how we think and reason and, as such, offers a useful tool to both learners and researchers.

Keywords: communication, embodied cognition, expert, learning, novice, speech, transitional knowledge, visuospatial thinking, working memory

Introduction

When people talk, they move their hands. These hand movements produced in conjunction with speech are called *gestures*. Like spoken language, gestures have the potential to eveal our thinking. But because gestures use a different representational format than speech does, they have the potential to reveal aspects of our thinking that are not evident in speech. Gesture thus offers a useful tool for learning about, and possibly changing, how we think.

We begin by situating gesture within the world of nonverbal behavior and highlighting why we think gesture, a nontraditional topic for a handbook on higher cognition, could contribute to our understanding of thinking and reasoning. We then take the first step in the argument that gesture plays a role in thinking by showing that gesture is not mere hand waving. It conveys substantive information and, importantly, can reveal thoughts not found in the speech it accompanies. Gesture thus offers a unique window into the mind of the speaker. We then provide evidence that a speaker's spontaneous gestures often presage the next steps in the speaker's thinking and learning. Finally, we explore the purpose gesture serves (the functions of gesture) and the processes underlying its production (the mechanisms of gesture). We end with thoughts about how the study of gesture can continue to contribute to our understanding of the mind.

What Is Gesture?

In 1969, Ekman and Friesen outlined five categories of nonverbal behaviors produced during communication, thus framing the field of nonverbal communication. These behaviors vary according to where they are produced, how they relate to speech, and whether they are under conscious control. (p. 632)

Two behaviors—*emblems* and *illustrators*—are what people typically mean when they use the term *gesture*. Emblems are conventionalized movements of the hand that have word- or phrase-like meanings and can, in fact, substitute for words. Take, for example, the OK emblem (thumb and index finger touch and form a circle) or the thumbs-up emblem. Emblems share many properties with spoken words and with the signs in conventional sign languages of the deaf: They are consciously produced with the intent to communicate; they encode information arbitrarily; and they adhere to standards of well-formedness. Just as one can mispronounce a word or sign, it is possible to produce the wrong form of an emblem (imagine producing the OK emblem with the thumb and fourth finger—it just doesn't work). Because they are codified, emblems can stand on their own and, in fact, are often produced without speech.

In contrast, illustrators depend on speech for their meaning. Because they are always produced with speech, they take on the intentionality of speech. However, illustrators rarely come under conscious control, and they do not have a right or wrong form. Take, for example, a speaker who says that she ran upstairs while gesturing her trajectory with her hands; she can carve out her pathusing a pointing hand, an open palm, or any other hand shape. In general, illustrators convey information holistically and imagistically and thus differ from speech, which conveys information componentially and categorically (Goldin-Meadow, 2003; McNeill 1992). As a result, illustrators have the potential to reveal aspects of thinking not evident in speech. It is because illustrators are produced as part of an intentional communicative act, but are constructed at the moment of speaking, that they are of interest to us. They participate in communication, yet they are not part of a codified system.

We focus in this chapter on illustrators, called *gesticulation* by Kendon (1980) and plain old *gesture* by McNeill (1992), the term we use here. Thus, for the most part, we ignore emblems, as well as the three remaining nonverbal behaviors identified by Ekman and Friesen (1969): *Affect displays*, whose primary site is the face, convey the speaker's emotions, or at least those emotions that the speaker does not wish to mask (Ekman, Friesen, & Ellsworth, 1972). *Regulators*, which typically involve head movements or slight changes in body position, maintain the give and take between speaker and listener and help pace the exchange. *Self-adaptors*, which are fragments or reductions of previously learned adaptive hand movements, are maintained by habit; for example, smoothing the hair, pushing glasses up the nose even when they are perfectly positioned, holding or rubbing the chin.

Gestures can mark the tempo of speech (beat gestures), point out referents of speech (deictic gestures), or exploit imagery to elaborate the contents of speech (iconic or metaphoric gestures). One question that is ripe for future research is whether these different types of gestures serve different functions and are served by different mechanisms. There is, in fact, evidence that beats and iconic/metaphoric gestures respond differently to the presence or absence of a listener (Alibali, Heath, & Myers, 2001), and that beat gestures are affected less by variation in the conceptual difficulty of speech than iconic or metaphoric gestures (Kita & Davies, 2009). Further research is needed to verify and explain these patterns. For now, we focus on deictic, iconic, and metaphoric gestures, as these are the gestures that have the potential to tell us the most about what a speaker is thinking.

Gesture Is Not Mindless Hand Waving and Often Reveals Thoughts Not Found in Speech

Gestures are interesting because they appear to provide a unique window onto thinking in that they reveal reliable information about a speaker's thoughts not evident in other behaviors. Accordingly, gesture can be a useful tool for exploring thinking and reasoning. As an example, gesture can reveal information about a speaker's prior motor experience that is not expressed in the accompanying speech. Cook and Tanenhaus (2009) asked adults to explain their solutions to the Tower of Hanoi problem after either solving the problem on the computer or solving it with real disks. The problem-solvers' verbal explanations were identical across the two groups (naïve observers could not distinguish the explanations produced by adults who had solved the problem on the computer from those produced by adults who had solved the problem using real disks). But their gestures differed. Adults who had solved the problem with real disks traced the trajectory of the disk with their hands (they mimed moving the disk up and over each peg). In contrast, adults who had solved the problem on the computer moved their hands laterally, mimicking the way the disks are moved on the screen (i.e., they do not have to be taken off the pegs before they are moved). The adults thus provided reliable cues about the problem-solving experiences they had had, cues that were not evident in their speech (Cook & Tanenhaus, 2009). **(p. 633)**

Gesture is not limited to displaying motor information and has been shown to reveal conceptual knowledge as well. Consider a child asked to participate in a series of Piagetian conservations tasks—the experimenter pours water from a tall, thin glass into a short, wide dish and asks the child whether the amount of water is still the same after the pouring. To succeed on this task and understand conservation of quantity, children need to integrate information across multiple dimensions—the height of the water in the container and its width. Nonconserving children focus on only one dimension, height or width, but not both. However, at times, a child will focus on one dimension in speech but provide evidence that he understands something about the importance of the second dimension in gesture. The child says that the amount of water is “different because this one is taller than that one,” thus focusing on the height of the water in speech. At the same time, he places a narrow C-shaped hand near the tall thin container, followed by a wider C-shaped hand near the short wide container, thus focusing on width in gesture—he displays knowledge of the second dimension *only* in his hands (Church & Goldin-Meadow1986;). Note that children need to appreciate the compensatory relation between height and width in order to understand conservation of liquid quantity. Although this child appears to be firmly convinced that pouring the water alters its quantity, his hands reveal the first inkling that he may be ready to change his mind.

As a second example, gesture reveals knowledge that is relevant to understanding mathematical equivalence but is not evident in speech. The child is asked to solve problems like 3 + 4 + 6 = __ + 6. To solve these problems correctly, children need to consider the relation between the two sides of the equation rather than simply adding up all of the numbers on the left side of the equation, or adding up all of the numbers in the problem (two common errors that children make when solving problems of this type). As in the conservation example, children sometimes produce gestures that reflect problem representations not expressed in the accompanying speech. For example, on the 3 + 4 + 6 = __ + 6 problem, a child puts 19, an incorrect answer, in the blank and says, “I added the three, the four, the six, and the six to get nineteen” (an add-all-numbers strategy). At the same time, the child sweeps her left hand under the left side of the equation and then produces the same sweeping motion under the right side of the equation (an equalizer strategy), thus displaying an awareness that the equation has two sides that should be treated alike (Alibali & Goldin-Meadow1993; Perry, Church, & Goldin-Meadow 1988;). Here again, the child displays an incorrect understanding of the problem in speech, but her hands reveal the first inkling that she may be ready to change her mind.

Gesture reveals aspects of children's early cognitive development at a variety of ages and with respect to a variety of tasks. For example, toddlers reveal an understanding of one-to-one correspondence in the gestures they use in early counting before they display the same level of understanding in speech, and successful counting is associated with these gestural behaviors (Graham, 1999). Preschoolers (particularly boys) reveal an ability to mentally rotate shapes in their gestures not evident in their speech, and children whose gestures portrayed the spatial transformations were particularly successful at solving the mental transformation problems (Ehrlich, Levine, & Goldin-Meadow 2006;). Finally, early elementary school children solving balance problems reveal an understanding of the problems in their gestures that is not found in their speech (Pine, Lufkin, Kirk, & Messer, 2007), as do sixth grade children learning about plate tectonics (Singer, Radinsky, & Goldman, 2008) and preschool children learning to solve simple problems involving gears (Boncoddo, Dixon, & Kelley, 2010). Gesture can thus be used to make reliable inferences about children's thinking across development.

Adults also reveal knowledge in their gestures that they do not display in their speech. For example, Alibali and colleagues (1999) asked adults first to describe algebra word problems about constant change, and then to indicate how they would go about solving the problems. The problems could be solved using either a discrete or continuous problem-solving strategy. Adults would often express one type of strategy in speech (e.g., continuous) while at the same time expressing the other type of strategy in gesture (discrete). Interestingly, speech and gesture taken together provided a more accurate picture of the strategy the adults planned to use to solve the problem than speech alone. Along the same lines, Garber, and Goldin-Meadow (2002) found that speech and gesture taken together provided insight into the moments when adults (and children) were considering alternative routes in solving the Tower of Hanoi problem, moments that were not detectable from speech alone.

Finally, we see the same phenomenon in children at the early stages of language learning. For example, (p. 634) when children begin to express causal relationships in speech, 3-year-olds use gesture to reinforce the goal of an action and 5-year-olds use gesture to add information about the instrument or direction of the action, information that is often not found in the accompanying speech; for example, producing an iconic *throw* gesture that adds information about the instrument to the utterance, "he broke the window" (GÖksun, Hirsh-Pasek, & Golinkoff 2010). As another example, when children begin to describe motion events in speech (e.g., "it went under there"), gesture is often used to reinforce or add information about manner, path, source, and endpoint. The type of information children choose to convey in gesture reflects not only their understanding of the event but also the linguistic framing of the particular language they are learning. For example, English allows speakers to combine manner and path within a single clause ("he rolls down"), and the gestures English speakers produce parallel this arrangement (the hand rolls as it moves down); in contrast, Turkish allows speakers to separate manner and path into separate clauses (the analog in English would be "he goes down by rolling"), and the gestures Turkish speakers produce reflect this structure (the hand rolls in place, followed by the hand moving down) (Özyürek, Kita, Allen, Furman, & Brown, 2005; Özyürek & Özç aliskan, 2000). Cross-linguistic studies of gesture can thus provide insight into how children come to describe events in the manner typical of their language.

Gestures Presage Next Steps in Thinking and Learning

Gestures not only reveal a person's thinking at the time that they are produced, but they also forecast subsequent changes in thinking. Gesture has been found to reliably predict future thinking across a wide variety of domains. In fact, the data suggest that gesture is often a more useful predictor of subsequent thinking than the concurrent speech. We begin by examining gesture's ability to foreshadow changes in child language learning.

Learning Language

Children's early gestures have been shown to foreshadow their subsequent vocabulary development (Bavin et al., 2008; Goodwyn & Acredolo, 1993; Rowe & Goldin-Meadow, 2008, 2009; Rowe, Özçaliskan, & Goldin-Meadow 2008;). For example, a child's early deictic gestures reliably predict which nouns are likely to enter that child's spoken vocabulary in the next 3 months (Iverson & Goldin-Meadow2005;).

Early gesture not only predicts the particular words children are likely to learn but also when and how those words are combined with one another. A child's early single-word utterances are often accompanied by gesture, and the relation between these early gestures and the speech they accompany reliably predicts when the child will produce her first two-word utterance. Children whose gestures overlap in meaning with the accompanying speech (e.g., pointing at a cup while saying “cup”) are likely to remain in the single-word stage for many months. In contrast, children whose gestures convey a different meaning from the accompanying speech (e.g., pointing at a cup while saying “mine”) are likely to begin combining words into two-word combinations within the next few months (Goldin-Meadow & Butcher, 2003; Iverson & Goldin-Meadow2005;). In fact, the particular constructions expressed in gesture + speech combinations can be used to predict the emergence of the same constructions in speech later in development. For example, a child who conveys an action predicate plus an object argument in speech and gesture (e.g., “open” combined with a point at a box) is likely to produce an action predicate + object argument construction entirely in speech (“open box”) several months later (Özç aliskan & Goldin-Meadow2005;).

Gesture continues to forecast children's verbal milestones beyond the transition from one-word to two-word speech. For example, children produce their first complex sentence containing two predicates in gesture and speech (e.g., “I like it,” said while producing an *eat* gesture) several months before producing their first complex sentence entirely in speech (“I like eating it;” Özç aliskan & Goldin-Meadow2005;). Interestingly, although children rely on gesture to produce the first instance of a construction (e.g., a predicate plus one argument, “give” + point at cookie), once the construction is established in their repertoire, children are no more likely to use gesture to flesh out the construction than they are to use speech. For example, they are just as likely to produce their first predicate plus three arguments entirely in speech (“*you* see my *butterfly* on my *wall*”) as they are to produce their first predicate plus three arguments in gesture and speech (“*Daddy* clean all the bird *poopie*” + point at *table*) (Özç aliskan & Goldin-Meadow2009;). Gesture thus acts as a harbinger of linguistic steps only when those steps involve new constructions, not when the steps merely flesh out existing constructions. (p. 635)

As these findings suggest, gesture is not a global index of subsequent linguistic change but rather an indication of specific changes. Rowe, and Goldin-Meadow (2009) observed 52 children interacting with their caregivers at home and found that gesture use at 18 months *selectively* predicted lexical versus syntactic skills at 42 months, even with early child speech controlled. Specifically, the number of different meanings children conveyed in gesture at 18 months predicted the size of their spoken vocabularies at 42 months, but the number of gesture + speech combinations did not. In contrast, the number of gesture + speech combinations, particularly those conveying sentence-like ideas, produced at 18 months predicted sentence complexity at 42 months, but meanings conveyed in gesture did not. Particular milestones in vocabulary and sentence complexity at age 3 1/2 years can thus be predicted from the way children moved their hands 2 years earlier.

Importantly, not only does gesture predict language development in typically developing children, but it also predicts subsequent language development in atypical populations. For example, some children who are late talkers will “catch up” to their typically developing peers, whereas others will continue to have persistent delays in language production. The interesting result is that early gesture can predict which children will catch up and which children will not (Thal, Tobias, & Morrison, 1991; Thal & Tobias, 1992); the children who caught up performed well on two gesture tasks: They could imitate object-related gestures produced by the experimenter (e.g., making a toy airplane fly), and they could reproduce a series of familiar, scripted actions modeled by an experimenter (e.g., feeding a teddy bear by putting him in a highchair, putting on his bib, feeding him an apple, and wiping his mouth). Gesture can also predict which children with early unilateral focal brain injury are likely to remain delayed with respect to vocabulary development, and which children are likely to move into the normal range. Children with brain injury who produced a repertoire of gestures at 18 months comparable to the repertoire of gestures produced by typically developing 18-month-old children were subsequently within the normal range of spoken vocabulary development at 22, 26, and 30 months. In contrast, children with brain injury whose gesture production at 18 months was outside of the typical range continued to show delays in vocabulary development at 22, 26, and 30 months (Sauer, Levine, & Goldin-Meadow 2010;). As a final example, early gesture appears to be a more robust predictor of subsequent language development in children with autism than other social communication factors (Luyster, Kedlec, Carter, & Tager-Flusberg, 2008; see also Smith, Mirenda, & Zaidman-Zait 2007;). Gesture is thus an early marker that can be used to determine whether children whose language-learning trajectory has the potential to go astray will, in fact, experience delay. In this sense, gesture is a promising tool for diagnosing persistent delay.

Learning Other Cognitive Tasks

Children enter language learning hands first. But they continue to gesture even after having mastered the rudiments of language. At that point, children's gestures begin to forecast changes in their thinking in other areas of cognitive development. One important experimental difference between the studies of gesture in learning language versus learning other cognitive tasks is that the language studies are all longitudinal observations of children in naturalistic settings. We see variability in the gestures children spontaneously produce at an early time point, and we use that variability to predict the onset of linguistic constructions at a later time point. We assume that the early gesture producers are ready to learn these linguistic constructions and need only more time or more input to do so.

In contrast, the studies of children learning other cognitive tasks tend to be short-term experimental manipulations. We again see variability in the gestures children spontaneously produce, this time with respect to a particular task, say, conservation of liquid quantity. But rather than wait for the children to experience additional input, we give the children instruction in the task and observe which children profit from that instruction. Recall the child described earlier who talked about the height of the water in speech but indicated its width in gesture. Although this child says that the amount of water is different when it is poured from one container to another (i.e., he is a nonconserver), his gestures indicate that he knows more about the task than his words indicate. And, indeed, when given instruction in conservation, this child is likely to make progress on the task—more likely than a child who focuses on the height of the water in both speech and gesture (Church & Goldin-Meadow1986;).

As another example, consider the child described earlier who was asked how she arrived at her incorrect answer to a mathematical equivalence problem and produced an add-all-numbers strategy in speech while (p. 636) at the same time producing an equalizer strategy in gesture. Here again, the child's gestures indicate that she knows more about mathematical equivalence than her words indicate. When given instruction in the problem, the child is likely to profit from that instruction and learn how to solve problems of this type correctly—more likely than a child who gives an add-all-numbers strategy in both speech and gesture (Perry, Church, & Goldin-Meadow 1988;). Moreover, when children's responses are charted during the course of instruction, we can see a child systematically progress through three periods characterized by the relation between gesture and speech—the child produces *(1)* the same strategy in both speech and gesture and that strategy is incorrect (e.g., add-all-numbers); *(2)* two different strategies, one in speech (e.g., add-all-numbers) and a different one in gesture (e.g., equalizer); *(3)* the same strategy in both speech and gesture but now the strategy is correct (e.g., equalizer) (Alibali & Goldin-Meadow1993;). If, as in this case, only one of the modalities conveys a correct strategy, that correct strategy is often found in gesture rather than speech. Gesture, when taken in relation to speech, signals that the child is ready to take the next step in learning about mathematical equivalence. Interestingly, when a child fails to pass through step (2) and goes directly from step (1) to step (3), the child's understanding of mathematical equivalence is relatively fragile; in particular, the child is unable to generalize the knowledge gained during instruction and does not retain the knowledge on a follow-up test (Alibali & Goldin-Meadow1993;).

We see this phenomenon on a variety of tasks and ages. For example, as described earlier, elementary school children asked to reason about balance often express new ideas about the task in gesture before expressing these same ideas in speech (Pine et al., 2007). When given instruction in the task, these children are the ones most likely to benefit from that instruction (Pine, Lufkin, & Messer, 2004). A similar effect has been found in adult learners asked to predict which way the last gear in a configuration of gears will turn (Perry & Elder, 1997) or asked to draw the stereoisomer of a molecule (Larson et al., 2010). In both cases, adults who display task-relevant information in their gestures not found in their speech are particularly likely to make progress on the task after getting instruction in the task.

It is clear that gesture offers a window onto thinking, and that the picture provided by gesture is often different from the view provided by speech. But why does gesture offer this privileged view? We explore first the functions gesture serves and then the mechanisms underlying its production to better understand why and how gesture precedes and predicts our thinking and reasoning.

The Functions Gesture Serves: What Does Gesture Do?

Communication: The Impact of Gesture on the Listener

We now know that speakers' gestures reveal their thoughts. Accordingly, one function that gesture could serve is to convey those thoughts to listeners. For gesture to serve this function, listeners must be able to extract information from the gestures they see. And, indeed, there is considerable evidence that listeners can use gesture as a source of information about the speaker's thinking (e.g., Graham & Argyle, 1975; McNeil, Alibali, & Evans, 2000).

The ability of listeners to glean information from a speaker's gestures can be seen most clearly when the gestures convey information that cannot be found anywhere in the speaker's words. Take, for example, the Cook and Tanenhaus (2009) Tower of Hanoi study described earlier in which speakers conveyed information about the trajectory a disk followed as it was moved from one peg to another—either an arced trajectory that went up and over the peg, or a lateral trajectory that ignored the peg. This information was *not* represented in the speakers' words. Listeners who saw the arced gestures were more likely to move the disk up and over the peg when they were later asked to solve the Tower of Hanoi problem on the computer (where it is not necessary to arc the disks to move them) than listeners who saw the lateral gestures (Cook & Tanenhaus, 2009). The listeners had not only read the action information off of the speakers' gestures, but that information had had an effect on their own subsequent actions.

Adults can also glean information from child speakers. When adult listeners are asked to describe the responses child speakers give on a conservation task, the adults frequently describe information that the children expressed *only* in gesture and not in speech (Goldin-Meadow & Momeni Sandhofer, 1999), making it clear that listeners can glean substantive information from speakers' gestures.

Perhaps the clearest example of this phenomenon is when the listener translates the information conveyed in the speaker's gestures into speech. Take, for example, a listener retelling a story in which the speaker said, “She whacks him one,” while producing a punching gesture. The listener subsequently (p. 637) redescribed this event as “She punches Sylvester out” (Cassell, McNeill, & McCullough, 1999); she had not only seen and interpreted the speaker's punching gesture but also integrated the information into her speech (see also Goldin-Meadow, Kim, & Singer, 1999; Goldin-Meadow & Singer, 2003). Similarly, mothers of young language-learning children frequently respond to their children's early gestures by translating them into speech (e.g., saying, “Yes, the bird is napping,” in response to a child's point at a bird produced while saying “nap;” Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007).

Not surprisingly, listeners increase their reliance on the speaker's gestures in situations where speech is difficult to understand; for example, when there is noise in the speech signal (Holle, Obleser, Rueschemeyer, & Gunter, 2010; Rogers 1978; Thompson &

Massaro, 1986, 1994). Listeners are also particularly influenced by gesture when the spoken message is relatively complex (McNeil, Alibali, & Evans, 2000).

Gesture can even affect the information listeners glean from the accompanying speech. Listeners are faster to identify a speaker's referent when speech is accompanied by gesture than when it is not (Silverman, Bennetto, Campana, & Tanenhaus, 2010). When processing speech that is accompanied by gesture conveying the same information, listeners are *more* likely to glean the message from speech than when processing speech accompanied by no gesture (Beattie & Shovelton, 1999, 2002; Graham & Argyle, 1975; McNeil et al., 2000; Thompson & Massaro, 1994). Conversely, when processing speech that is accompanied by gesture conveying different information, listeners are *less* likely to glean the message from speech than when processing speech accompanied by no gesture (Goldin-Meadow & Momeni Sandhofer, 1999; Kelly & Church, 1998; McNeil et al., 2000). In addition, more incongruent gestures lead to greater processing difficulty than congruent gestures (Kelly, Özyürek, & Maris 2010). The effect that gesture has on listeners' processing is thus linked to the meaning relation between gesture and speech. Moreover, listeners cannot ignore gesture even when given explicit instructions to do so (Kelly, Özyürek, & Maris 2010; Langton, O'Malley, & Bruce 1996), suggesting that the integration of gesture and speech is automatic.

Like adults, children are able to extract information from a speaker's gestures, even when the information is not conveyed in the accompanying speech (Kelly & Church, 1997). Very young children can use gesture as a source of information to support word learning (Booth, McGregor, & Rohlfing, 2008; McGregor, Rohlfing, Bean, & Marschner, 2008). By age 3 years, children are able to integrate information across speech and gesture (Kelly, 2001; Morford & Goldin-Meadow1992; Thompson & Massaro, 1986). However, the influence that gesture has on how speech is interpreted does appear to increase throughout childhood (Thompson & Massaro, 1986, 1994).

The fact that gesture can communicate information to listeners suggests that gesture might be particularly helpful in teaching and learning situations. Indeed, child listeners have been shown to learn more from a lesson that contains gesture than from a lesson that does not contain gesture (Church, Ayman-Nolley, & Mahootian 2004; Valenzeno, Alibali, & Klatzky, 2003), even when the gestures are not directed at objects in the immediate environment (Ping & Goldin-Meadow2008;). Interestingly, even though communication often suffers when speakers produce gestures that convey different information from their speech (Goldin-Meadow & Momeni Sandhofer, 1999; Kelly & Church, 1998; McNeil et al., 2000), children learning mathematical equivalence seem to benefit most from instruction that contains one correct strategy in speech and a different correct strategy in gesture (Singer & Goldin-Meadow2005;); that is, from instruction in which gesture conveys different information from speech. One possibility is that, in these instances, the additional information in gesture makes it more likely that one of the representations in the instruction matches the child's next developmental state and, in this way, facilitates learning.

The process by which gesture affects the listener is currently being explored using a variety of brain imaging paradigms. Using functional magnetic resonance imaging (fMRI), researchers have found that gesture activates areas associated with language processing, including Broca's area (Skipper, Goldin-Meadow, Nusbaum, & Small, 2007; Willems, Özyürek, &Hagoort 2007). Gesture also appears to affect how processing is organized by influencing the connectivity among the relevant brain regions (Skipper, Goldin-Meadow, Nusbaum, & Small, 2007).

Using electroencephology (EEG), a number of researchers have demonstrated that the relation between gesture and speech can modulate brain activity. Gestures that are semantically anomalous with respect to the accompanying speech are (p. 638) associated with a more negative N400 waveform (Bernardis, Salillas, & Caramelli, 2008; Holle & Gunter, 2007; Kelly, Kravitz, & Hopkins, 2004; Özyürek Willems, Kita, & Hagoort, 2007; Wu & Coulson, 2005, 2007); the N400 is known to be sensitive to incongruent semantic information (Kutas & Hillyard, 1984). For example, gestures conveying information that is truly incongruent with the information conveyed in speech (gesturing *short* while saying "tall") produce a large negativity at 400 ms (Kelly et al., 2004). Interestingly, gestures conveying information that is different from, but complementary to, information conveyed in speech (gesturing *thin* while saying "tall" to describe a tall, thin container) are processed no differently at this stage from gestures that convey the same information as speech (gesturing *tall* while saying "tall;" Kelly et al., 2004). Neither one produces a large negativity at 400 ms; that is, neither one is recognized as a semantic anomaly. It is important to note, however, that at early stages of sensory/phonological processing (P1-N1 and P2), speech accompanied by gestures conveying different but complementary information (e.g., gesturing *thin* while saying "tall") is processed differently from speech accompanied by gestures conveying the same information (gesturing *tall* while saying "tall"). Thus, complementary differences between the modalities (i.e., the information conveyed in gesture is different from, but has the potential to be integrated with, the information conveyed in speech) are noted at early stages of processing, but not at later, higher level stages.

Gestures can affect the message listeners glean from speakers. Nonetheless, it is not clear that speakers *intend* their gestures to be communicative. Some gestures are meant to be communicative; for example, gestures that are referred to explicitly in the accompanying speech ("this one," accompanied by a pointing gesture). However, it is not clear whether gestures that are not explicitly referenced in speech are intended to be communicative. One way to explore this issue is to vary whether speakers and listeners have visual access to one another. The question is whether speakers will gesture even when their listeners cannot see them and thus cannot acquire any information from those gestures. The answer is that speakers gesture less frequently when their listeners do not have visual access to gesture, particularly iconic gestures (Alibali et al., 2001; Cohen 1977; Emmorey & Casey, 2001). However, speakers do not stop gesturing completely when their listeners cannot see them (Alibali et al., 2001; Bavelas, Chovil, Lawrie, &

Wade, 1992; Bavelas, Gerwing, Sutton, & Prevost, 2008; Cohen 1977; Cohen & Harrison, 1973; Emmorey & Casey, 2001; Krauss, Dushay, Chen, & Rauscher, 1995; Rimé, 1982), suggesting that gesture may be produced for the benefit of the speaker as well as the listener. The next section explores the functions gesture can serve for the speaker.

Cognition: The Impact of Gesture on the Speaker

Facilitating Lexical Access

Gestures have long been argued to help speakers "find" words, that is, to facilitate lexical access (Rauscher, Krauss, & Chen, 1996). Consistent with this hypothesis, speakers are more likely to gesture when they are producing unrehearsed speech (Chawla & Krauss, 1994), when they are about to produce less predictable words (Beattie & Shovelton, 2000), and when lexical access is made more difficult (Rauscher, Krauss, & Chen, 1996). Temporally, gestures precede less familiar words to a greater degree than they precede more familiar words (Morrel-Samuels & Krauss, 1992). And brain-damaged patients with difficulties in lexical access (that is, patients with aphasia) gesture at a higher rate than patients with visuospatial deficits (Hadar, Burstein, Krauss, & Soroker, 1998). These findings suggest that gesture is associated with difficulties in lexical access. More direct evidence that gesture plays a role in lexical access comes from reports that speakers are more successful at resolving tip-of-the-tongue states when they are permitted to gesture than when they are not, for both adult (Frick-Horbury & Guttentag, 1998) and child (Pine, Bird, & Kirk, 2007) speakers (but see Beattie & Coughlan, 1999).

Reducing Demands on Conceptualization

Speakers gesture more on problems that are conceptually difficult, even when lexical demands are equated (Alibali, Kita, & Young, 2000; Hostetter, Alibali, & Kita, 2007; Kita & Davies, 2009; Melinger & Kita, 2007). As an example, when adult speakers are asked to describe dot patterns, they gesture more when talking about patterns that do not have lines connecting the dots (patterns that are more difficult to conceptualize) than patterns that do have lines (Hostetter et al., 2007). As a second example, children who are asked to solve Piagetian conservation problems (problems that require conceptualization) gesture more than when they are (p. 639) simply asked to describe the materials used in the conservation problems (Alibali et al., 2000).

Gesture may be particularly effective in reducing conceptual demands in visuospatial tasks, as gesture is a natural format for capturing spatial information. Gesture has, in fact, been found to facilitate visuospatial processing in speakers, either by maintaining visuospatial information in memory (Morsella & Krauss, 2004; Wesp, Hesse, Keutmann, & Wheaton, 2001) or by facilitating packaging of visuospatial information for spoken language (Kita, 2000). Gesture can also facilitate transformation of spatial information in memory; when performing mental rotation tasks, adults are particularly successful if they produce gestures (Chu & Kita, 2008; Schwartz & Black, 1999) or hand movements

(Wexler, Kosslyn, & Berthoz, 1998; Wohlschlager & Wohlschlager, 1998) consistent with the actual rotation that is to be performed, or consistent with the movement that would activate the rotation (e.g., a pulling gesture that mimics pulling a string from a spool to make the spool turn; Schwartz & Holton, 2000).

Although these findings are consistent with the idea that gesturing reduces demands on conceptualization, the relevant studies manipulated conceptualization difficulty and observed the effects of the manipulation on gesturing, finding that conceptualization difficulty and gesturing go hand in hand. But to be certain that gesturing plays a role in reducing conceptualization demands (as opposed to merely reflecting those demands), future work will need to manipulate gesture and demonstrate that the manipulation reduces the demands on conceptualization.

Reducing Demands on Working Memory

Gesturing has been shown to reduce demand on speakers' working memory. When asked to remember an unrelated list of items while explaining how they solved a math problem, speakers are able to maintain more items in verbal working memory (and thus recall more items) when they gesture during the explanation than when they do not gesture. This effect has been found in both children and adults (Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001). Interestingly, the effect has also been found for items in visual working memory (i.e., speakers maintain more items in visual working memory when they gesture during their explanations than when they do not gesture; Wagner, Nusbaum, & xsGoldin-Meadow 2004;), suggesting that gesturing lightens the load on working memory whether the stored items are visual or verbal. In addition, gesturing reduces demand on working memory even when the gestures are not directed at visually present objects (Ping & Goldin-Meadow2010;), suggesting that gesturing confers its benefits by more than simply tying abstract speech to objects directly visible in the environment.

Importantly, it is not just moving the hands that reduces demand on working memory—it is the fact that the moving hands convey meaning. Producing gestures that convey different information from speech reduces demand on working memory *less* than producing gestures that convey the same information in speakers who are experts on the task (Wagner et al., 2004). Interestingly, we find the opposite effect in speakers who are novices—producing gestures that convey different information from speech reduces demand on working memory *more* than producing gestures that convey the same information as speech (Ping & Goldin-Meadow2010;). In both cases, however, it is the meaning relation that gesture holds to speech that determines, at least in part, the extent to which the load on working memory is reduced.

Linking Internal Representations to the World

Gesturing may help link the speaker's internal representations to the physical and communicative environment. Deictic gestures, in particular, may facilitate speakers' use of the surrounding space (Ballard, Hayhoe, Pook, & Rao, 1997). For example, for children learning to count, gesture seems to be important in coordinating number words with objects and in keeping track of which objects have already been counted (Saxe & Kaplan, 1981). Alibali and DiRusso (1999) explored gesture's role in children's counting by comparing three conditions: the child gestured while counting, the child was restricted from gesturing while counting, and the child watched a puppet gesture while the child counted. They found that children were most accurate when their counting was accompanied by gesture, theirs or the puppet's. But they were least likely to make errors coordinating number words and objects when the children themselves produced the gestures.

However, as mentioned earlier, gestures do not have to be directed at visible objects in order for speakers to benefit from gesturing. Ping, and Goldin-Meadow (2010) measured demand on working memory in children asked to remember (p. 640) an unrelated list of items while explaining their responses to a conservation task. Children were told to gesture on half the trials and not to gesture on the other half. One group gave their explanations with the task objects present; the other group gave their explanations with the task objects out of view. Children remembered more items, reflecting a reduced demand on working memory, when they gestured during their explanations than when they did not gesture, even when the objects were not visible. Gesturing does not need to be tied to the physical environment in order to be effective. Indeed, over the course of learning a task, gestures can become more and more removed from the immediate physical environment, eventually becoming internalized (Chu & Kita, 2008).

Activating Old Knowledge and Bringing in New Knowledge

Gesturing can activate knowledge that the speaker has but does not express. Broaders, Cook, Mitchell, and Goldin-Meadow (2007) asked children to explain how they solved six mathematical equivalence problems with no instructions about what to do with their hands. They then asked the children to solve a second set of comparable problems and divided the children into three groups: Some were told to move their hands as they explained their solutions to this second set of problems; some were told not to move their hands; and some were given no instructions about their hands. Children who were told to gesture on the second set of problems added strategies to their repertoires that they had not previously produced; children who were told not to gesture and children given no instructions at all did not. Most of the added strategies were produced in gesture and not in speech and, surprisingly, most were correct. In addition, when later given instruction in mathematical equivalence, it was the children who had been told to gesture, and who had added strategies to their repertoires, who subsequently profited from the instruction and learned how to solve the math problems. Being told to gesture thus encouraged children to express ideas that they had previously not expressed, which, in turn, led to learning.

But can gesture, on its own, create new ideas? To determine whether gesture can create new ideas, we need to teach speakers to move their hands in particular ways. If speakers can extract meaning from their hand movements, they should be sensitive to the particular movements they are taught to produce and learn accordingly. Alternatively, all that may matter is that speakers move their hands. If so, they should learn regardless of which movements they produce. To investigate these alternatives, Goldin-Meadow, Cook, and Mitchell (2009) manipulated gesturing during a math lesson. They found that children required to produce *correct* gestures learned more than children required to produce *partially correct* gestures, who learned more than children required to produce *no* gestures. This effect was mediated by whether, after the lesson, the children added information to their spoken repertoire that they had conveyed only in their gestures during the lesson (and that the teacher had not conveyed at all). The findings suggest that gesture is involved not only in processing old ideas but also in creating new ones. We may be able to lay the foundations for new knowledge simply by telling learners how to move their hands (see Cook, Mitchell & Goldin-Meadow2008; for related findings) or by moving our hands ourselves (children who see their teachers gesture a concept are likely to gesture themselves and, in turn, are likely to learn the concept; Cook & Goldin-Meadow2006;).

The Mechanism Underlying Gesture Production: Where Does Gesture Come From?

Gesture is not simply mindless hand waving. It offers a window onto speakers' thinking, affording access to information not available in the speakers' other behaviors. But gesture does more than simply externalize speakers' thinking. When speakers gesture, those gestures have an impact not only on their listeners but also on their own cognition. We next explore the mechanism that underlies gesture production.

Roots in Speech

Gestures are produced in conjunction with speech. One mechanism that could underlie the production of gesture is speech production; that is, the processes supporting speech production may naturally lead to gesture production.

It is clear that gesture and speech are inexorably linked. Congenitally blind speakers, who have never seen another person gesture, produce gestures when they speak, even when speaking to blind listeners (Iverson & Goldin-Meadow, 1997, 1998). Prior to speaking, children produce rhythmic hand movements in conjunction with their vocal babbling (Masataka, 2001). Although gestures are sometimes (p. 641) produced without accompanying speech, the vast majority of gestures are produced while speaking (McNeill, 1992), suggesting that speech and gesture production may share a single mechanism. Moreover, even when speakers do not produce overt gestures, recalling concrete and spatial words from definitions is associated with changes in muscle potentials in the arms (Morsella & Krauss, 2005). More generally, speaking is associated with increases in corticospinal excitability of hand motor areas (Meister et al., 2003; Seyal, Mull, Bhullar, Ahmad, & Gage, 1999; Tokimura, Tokimura, Oliviero, Asakura, & Rothwell, 1996). Listening to speech has also been associated with activity in the hand motor cortex (FlÖel, Ellger, Breitenstein, & Knecht, 2003). Production of speech and production of hand movements are thus tightly linked to one another, at both the behavioral and the neural level.

Gesture is linked to spoken language at every level of analysis, including the phonological level, lexical level, syntactic level, prosodic level, and conceptual level (as discussed earlier in the section on “The Functions Gesture Serves”). At the phonological level, producing hand gestures influences the voice spectra of the accompanying speech for deictic gestures (Chieffi, Secchi, & Gentilucci, 2009), emblem gestures (Barbieri, Buonocore, Dalla Volta, & Gentilucci 2009; Bernardis & Gentilucci, 2006), and beat gestures (Krahmer & Swerts, 2007). When phonological production breaks down, as in stuttering or aphasia, gesture production stops as well (Mayberry & Jacques, 2000, McNeill, Levy, & Pedelty, 1990). There are phonological costs to producing gestures with speech—producing words and deictic gestures together leads to long initiation times for the accompanying speech, relative to producing speech alone (Feyereisen, 1997; Levelt, Richardson, & Laheij, 1985). Viewing gesture also affects voicing in listeners' vocal responses to audiovisual stimuli (Bernardis & Gentilucci, 2006).

At the lexical level, as discussed earlier, gesturing increases when the speaker is searching for a word. More generally, gestures both reflect, and compensate for, gaps in a speaker's verbal lexicon. Gestures can package information in the same way that information is packaged in the lexicon of the speaker's language. For example, when speakers of English, Japanese, and Turkish are asked to describe a scene in which an animated figure swings on a rope, English speakers overwhelmingly use the verb “swing” along with an arced gesture (Kita & Özyürek, 2003). In contrast, speakers of Japanese and Turkish, languages that do not have single verbs that express an arced trajectory, use generic motion verbs along with the comparable gesture; that is, a straight gesture (Kita & Özyürek, 2003). But gesture can also compensate for gaps in the speaker's lexicon by conveying information that is not encoded in the accompanying speech. For example, complex shapes that are difficult to describe in speech can be conveyed in gesture (Emmorey & Casey, 2001).

At the syntactic level, as described earlier, gestures are influenced by the structural properties of the accompanying speech. For example, English expresses manner and path within the same clause, whereas Turkish expresses the two in separate clauses. The gestures that accompany manner and path constructions in these two languages display a parallel structure—English speakers produce a single gesture combining manner and path (a rolling movement produced while moving the hand forward), whereas Turkish speakers produce two separate gestures (a rolling movement produced in place, followed by a moving forward movement) (Kita & Özyürek, 2003; Kita et al., 2007). Gesture production also reflects the amount of information encoded in a syntactic structure. Speakers gesture more when producing an unexpected (and, in this sense, more informative) syntactic structure than when producing an expected structure (Cook, Jaeger, & Tanenhaus, 2009).

At the prosodic level, the movement phase of a speaker's gesture co-occurs with the point of peak prosodic emphasis in the accompanying clause in speech (Kendon, 1980; McClave 1998). And listeners make inferences about the perceived prominence of words in an utterance from the speaker's gestures (Krahmer & Swerts, 2007).

Gestures have also been linked to the conceptualization process involved in speaking, that is, the process by which speakers determine which information to linguistically encode in an utterance. Support for this hypothesis comes from studies showing that difficulty, or greater ambiguity about what to say, is associated with increases in gesture production (Alibali et al., 2000; Hostetter, Alibali, & Kita, 2007; Kita & Davies, 2009; Melinger & Kita, 2007). However, not all studies find that increases in conceptualization difficulty are associated with increases in gesture rate (Sassenberg & van der Meer, 2010).

An explanation on the evolutionary timespan for the close relationship between gesture and speech is that spoken language may have evolved from (p. 642) more primitive gestural communication systems (Corballis, 1992; Fitch 2000; Holden 2004). If so, modern-day gestures that are produced in conjunction with speech may represent vestigial activity of a prior system for communication. Gesture may continue to contribute functionally to spoken communication, as the findings in the previous section suggest, or may simply reflect the underlying organization of the system without being functionally involved in spoken language production.

Roots in Visuospatial Thinking

Gestures could also emerge from visuospatial thinking. Consistent with this hypothesis, speakers are likely to gesture when talking about things that are spatial or imageable (Alibali et al., 2001; Beattie & Shovelton, 2002, Krauss, 1998; Lavergne & Kimura, 1987; Rauscher et al., 1996; Sousa-Poza, Rohrberg, & Mercure, 1979) and when conveying information that has been acquired visually (as opposed to verbally, Hostetter & Hopkins, 2002). In addition, when speakers are restricted from gesturing, the spatial (Graham & Heywood, 1975) and/or imagistic (Rime, Schiarature, Hupet, & Ghysselinckx, 1984) content of the accompanying speech changes. Finally, brain-damaged patients with visuospatial deficits gesture less than comparable patients with lexical access deficits (Hadar et al., 1998).

In a striking example of the link between visuospatial representation and gesture production, Haviland (1993) described how a speaker of Guugu Yimithirr, an Australian language that uses an absolute rather than a relative reference frame to represent direction, adjusted his gesture production across two tellings of the same story so that his gestures were true to the actual spatial layout of the original event (i.e., his gestures were also absolute rather than relative). The speaker, describing how a boat overturned many years ago, produced a rolling motion away from his body when facing west since the boat had actually rolled from east to west. However, when telling the story on another occasion, he happened to be facing north rather than west. In this retelling, he produced the same rolling-over gesture, but this time his hands rolled from right to left rather than away from his body. The gesture was accurate with respect to the actual event (an east-to-west roll). Importantly, the speaker did not refer to the absolute spatial context of the original event in his speech.

Gestures are particularly likely to represent visuospatial thinking that involves transformations. For example, gestures frequently represent orientations and rotations of block locations (Emmorey & Casey, 2001), spatial transformations (Trafton et al., 2006), and component motions of entities in physics problems (Hegarty, Mayer, Kriz, & Keehner, 2005; see Hegarty & Stull, Chapter 31).

In addition to representing spatial information directly, gestures may also reflect metaphoric use of visuospatial representations. Speakers use a wide variety of spatial metaphors when representing nonspatial concepts, including time (Alverson, 1994; Clark 1973), mathematics (Lakoff & Nunéz, 2000), and emotions (Lakoff & Johnson, 1999). Moreover, these metaphoric representations are not simply linguistic conventions but can have an effect on information processing. For example, people's judgments about the meaning of a temporal expression like “the meeting has been moved forward 2 days” depends on how they envision themselves moving through space (Boroditsky & Ramscar, 2002). Gestures that are produced when talking about time are consistent with the underlying metaphoric mapping between space and time in the speaker's language (e.g., English speakers gesture in front of themselves when talking about the future, whereas speakers of Aymara gesture to their backs; Núñez & Sweetser, 2006). Producing appropriate hand movements can also facilitate comprehension of metaphoric expressions like “push the argument” (Wilson & Gibbs, 2007). Thus, gestures may reflect and engage visuospatial thinking when it is used metaphorically as well as when it is used literally.

Roots in Action

Hostetter and Alibali (2008) have proposed that gestures emerge from perceptual and motor simulations underlying the speaker's thoughts (see also Rimè & Schiaratura 1991). This proposal is based on recent theories claiming that linguistic meaning is grounded in perceptual and action experiences (Barsalou, 1999; Glenberg & Kaschak, 2002; Richardson, Spivey, Barsalou, & McRae, 2003; Zwaan, Stanfield, & Yaxley, 2002). If so, gesture could be a natural outgrowth of the perceptual-motor experiences that underlie language. Under this view, the richer the simulations of the experiences, the more speech will be accompanied by gesture.

Support for the hypothesis that gestures emerge out of motor processes comes from a study conducted by Feyereisen and Havard (1999) who explored whether certain types of imagery, including motor imagery, are likely to lead to gesture. Speakers (p. 643) were asked to describe motor activities (e.g., changing a tire, wrapping a present), visual scenes (e.g., rooms, landscapes), or abstract topics (e.g., women in politics, the death penalty). Motor imagery frequently resulted in iconic gestures, whereas abstract topics led to beat gestures. However, the weakness of the study is that topic and type of imagery were confounded. The action words generated to describe the topic, rather than motor imagery, might therefore have led to the frequent iconic gestures.

The study conducted by Cook and Tanenhaus (2009) that was described in an earlier section also explored the relation between motor imagery and gesture. In this study, speakers who performed the Tower of Hanoi task with real disks gestured differently from speakers who performed the task on the computer, even though their verbal descriptions were identical. The speakers who solved the problem with real disks produced gestures that simulated the actions they used to move the disks (i.e., they lifted the disk up and over the peg), suggesting that gestures can reflect motor representations. As another example, speakers gesture more when describing dot patterns that they constructed with wooden pieces than dot patterns that they viewed on a computer screen (Hostetter & Alibali, 2010).

But gestures do not merely reflect the action simulations that underlie the speaker's thinking; they can also influence which action components become part of the speaker's mental representation. Beilock, and Goldin-Meadow (2010) asked adults to first solve the Tower of Hanoi problem with real, weighted disks (TOH1). The smallest disk in the tower was the lightest and could be lifted with one hand; the biggest was so heavy that it required two hands. The adults were then asked to explain how they solved the problem, gesturing while doing so. After the explanation, they solved the problem a second time (TOH2). For some problem solvers (*No-Switch Group*), the disks in TOH2 were identical to TOH1, and they, not surprisingly, improved on the task (they solved TOH2 in fewer moves and in less time than TOH1). For others (*Switch Group*), the disk weights in TOH2 were reversed—the smallest disk was now the heaviest and could no longer be lifted with one hand. This group did not improve and, in fact, took more moves and more time to solve the problem on TOH2 than TOH1. Importantly, however, the performance on the *Switch* group on TOH2 could be traced back to the gestures they produced during the explanation task: The more they used one-handed gestures when talking about moving the smallest disk during the explanation, the worse they did on TOH2 (remember that the smallest disk on TOH2 in the *Switch* group could no longer be lifted with one hand). There was no relation between the type of gesture used during the explanation and performance on TOH2 in the *No-Switch* group simply because the smallest disk on TOH2 could be lifted using either one or two hands.

Beilock, and Goldin-Meadow (2010) suggested that the one-handed gestures speakers produced during the explanation task helped to consolidate a representation of the smallest disk as "light." This representation was incompatible with the action that had to be performed on TOH2 in the *Switch* group but not in the *No-Switch* group. If gesturing is responsible for the decrement in performance in the *Switch* group, removing gesturing should eliminate the decrement—which is precisely what happened. In a second experiment that eliminated the explanation phase and thus eliminated gesturing entirely, the *Switch* group displayed no decrement in performance and, in fact, improved as much as the *No-Switch* group (Beilock & Goldin-Meadow2010;). Thus, the switch in disks led to difficulties on TOH2 only when the adults gestured in between the two problem-solving attempts, and only when those gestures conveyed information that was incompatible with the speaker's next moves.

Note that disk weight is not a relevant factor in solving the Tower of Hanoi problem. Thus, when the speakers explained how they solved TOH1, they never talked about the weight of the disks or the number of hands they used to move the disks. However, it is difficult not to represent disk weight when gesturing—using a one-handed versus a two-handed gesture implicitly captures the weight of the disk, and this gesture choice had a clear effect on TOH2 performance. Moreover, the number of hands that the *Switch group* actually used when acting on the smallest disk in TOH1 did not predict performance on TOH2; only the number of one-handed gestures predicted performance. The findings suggest that gesture is adding action information to the speakers' mental representation of the task, rather than merely reflecting their previous actions. Gesturing about an action can thus solidify in mental representation the particular components of the action reflected in the gesture.

Conclusions and Future Directions

We know that the gestures speakers spontaneously produce along with their talk reflect their thoughts, (p. 644) and that those thoughts are often not expressed in the talk itself. Moreover, evidence is mounting that gesture not only reflects thought but also plays a role in changing thought. The next frontier is to figure out *how* gesture influences thinking.

We have seen that gesture serves a range of functions for both listeners (communicative functions) and speakers (cognitive functions). One question for future research is how these functions work together. For example, gesturing reduces demands on the speaker's working memory, and it can also introduce new information into the speaker's mental representations. Are these two functions synergistic? Recall that producing gestures that convey different information from speech is particularly effective in lightening demands on the novice's working memory. Moreover, seeing gestures that convey different information from speech is highly effective in teaching the novice new information. The parallel hints at a potential relation between the two functions and warrants additional study.

Another important question is whether the processes that are responsible for the effect gesture has on learning are unique to gesture. Gesture may be special only in the sense that it makes efficient use of ordinary learning processes; for example, cues may be more distinctive when presented in two modalities than in one, and speech and gesture may simply be an effective way of presenting information multimodally. On the other hand, it is possible that traditional principles of learning and memory (e.g., distinctiveness, elaboration, cue validity, cue salience, etc.) will, in the end, not be adequate to account for the impact that gesture has on learning; in this event, it will be necessary to search for processes that are specific to gesture.

We have also seen that gesture is served by a range of mechanisms and has roots in speech, visuospatial thinking, and action. Again, the question is how these processes work together. If current theories are correct that speech has an action base (Barsalou, 1999; Glenberg & Kaschak, 2002; Richardson et al., 2003; Zwaan et al., 2002), gesture may be a natural reflection of this foundation. We can then ask whether action holds a privileged position not only in gesture production but also in gesture's effect on thinking. For example, do gestures that closely resemble action (e.g., simulating the movement of the hands as they lift the disks in the Tower of Hanoi task) have a more powerful effect on the mental representations of the speaker than gestures that incorporate some, but not all, aspects of the action (e.g., tracing the trajectory of the disks as they are lifted, but including no information about how the hand was shaped as it moved the disk) or than gestures that are only abstractly related to action (i.e., metaphoric gestures)?

Another question for future research is whether gesture and action affect mental representations in the same way. Although gesturing is based in action, it is not a literal replay of the movements involved in action. Thus, it is conceivable that gesture could have a different impact on thought than action itself. Arguably, gesture should have less impact than action, precisely because gesture is “less” than action; that is, it is only a representation, not a literal recreation, of action. Alternatively, this “once-removed-from-action” aspect of gesture could have a more, not less, powerful impact on thought (see, for example, Goldin- Meadow & Beilock, 2010).

Finally, we can ask whether visuospatial thinking is privileged with respect to gesture. Gesture is an ideal medium for capturing spatial information, which leads to an important question about the mechanism that underlies gesture. Do domains that are inherently spatial (e.g., reasoning about the configuration of objects, as in organic chemistry) lend themselves to gesture more than nonspatial domains (e.g., reasoning about moral dilemmas)? Gesture's affinity with space also leads to questions about gesture's function. Does gesture affect cognitive processes more in spatial domains than in nonspatial domains? Is gesture effective in changing thinking because it can “spatialize” any domain (e.g., producing spatial gestures along with a description of a moral dilemma introduces spatial elements into the problem space and, in this way, allows spatial mechanisms to be brought to bear on the problem)?

The hope is that future work will allow us to build a model of exactly how speech and gesture emerge, both over ontogeny and in the moment during processing. In development, there is considerable evidence that early thoughts are often expressed in gesture prior to being expressed in speech, and that expressing those thoughts in gesture facilitates expressing them in speech. However, it is less clear whether gesture and speech have a similar relation during processing in the moment. Gestures often onset before the words they represent during production (McNeill, 1992) and, in fact, there is a precise relation in the timing of gesture to word—the more familiar the word, the smaller the gap between onset of gesture and onset of word (Morrel-Samuels & Krauss, 1992). But this timing relation need not reflect (p. 645) the process by which thoughts are translated into gesture and speech. It is possible that some thoughts can be accessed by gesture before being accessed by speech (thoughts that are less amenable to speech and perhaps privileged in gesture). It is also possible that some thoughts are accessed by gesture only after they have been packaged into a spoken representation, although the results we have reviewed here demonstrating a direct link between gesture and thinking may make this second possibility less plausible.

In sum, the spontaneous gestures we produce when we talk are not mindless hand waving. They not only reflect our thoughts, but they also have the potential to change the thoughts of others (our listeners) and even to change our own thoughts (as speakers). Gesture thus offers a tool that allows both learners and researchers to make new discoveries about the mind.

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