

Gesture's Role in Speaking, Learning, and Creating Language

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Abstract

When speakers talk, they gesture. The goal of this review is to investigate the contribution that these gestures make to how we communicate and think. Gesture can play a role in communication and thought at many timespans. We explore, in turn, gesture's contribution to how language is produced and understood in the moment; its contribution to how we learn language and other cognitive skills; and its contribution to how language is created over generations, over childhood, and on the spot. We find that the gestures speakers produce when they talk are integral to communication and can be harnessed in a number of ways. (a) Gesture reflects speakers' thoughts, often their unspoken thoughts, and thus can serve as a window onto cognition. Encouraging speakers to gesture can thus provide another route for teachers, clinicians, interviewers, etc., to better understand their communication partners. (b) Gesture can change speakers' thoughts. Encouraging gesture thus has the potential to change how students, patients, witnesses, etc., think about a problem and, as a result, alter the course of learning, therapy, or an interchange. (c) Gesture provides building blocks that can be used to construct a language. By watching how children and adults who do not already have a language put those blocks together, we can observe the process of language creation. Our hands are with us at all times and thus provide researchers and learners with an ever-present tool for understanding how we talk and think.

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WHY STUDY GESTURE?

The goal of this review is to explore the role that our hands play in communication and cognition. We focus on the hands for a number of reasons. First, hand movements during talk—better known as gestures—are ubiquitous. Speakers in all cultures gesture when they talk, and the topics that elicit gesture can be as simple as a child's board game (Evans & Rubin 1979) or as complex as kinship relations

(Enfield 2005). Even congenitally blind individuals, who have never seen anyone gesture, move their hands when they talk (Iverson & Goldin-Meadow 1998), which highlights the robustness of gesture in communication.

Equally important, the gestures that speakers produce when they talk do not go unnoticed by their listeners. For example, an interviewee is just as likely to be led astray by the interviewer's misleading gestures as by his misleading words. Asking the listener the open-ended question, "What else was the man wearing?" accompanied by a hat gesture (moving the hand as though donning a hat) elicits just as many hat responses as the pointed question, "What color was the hat that the man was wearing?"—in both cases, the man was not wearing a hat (Broaders & Goldin-Meadow 2010). Gesture is part of our conversations and, as such, requires our research attention.

Gesture plays a role in communication at a variety of timespans—in speaking at the moment, in learning language over developmental time, and in creating language over shorter and longer periods of time. We use this structure in organizing our review. We begin by exploring gesture's role in how language is processed in the moment—how it is produced and how it is understood. We then explore the role that gesture plays over development, initially in learning language and later, once language has been mastered, in learning other concepts and skills. Finally, we explore the role that gesture plays in creating language over generations (in deaf individuals who share a communication system and transmit that system to the next generation), over developmental time (in deaf children who do not have access to a usable model for language, spoken or signed), and on the spot (in adults who are asked to communicate without using speech).

Having shown that gesture is an integral part of communication, we end with a discussion of how gesture can be put to good use—how it can be harnessed for diagnosis and intervention in the clinic and for assessment and instruction in the classroom.

GESTURE'S ROLE IN LANGUAGE PROCESSING

Gesture Production and Its Role in Producing Language

The gestures that speakers produce along with their speech may actually help them to produce that speech. In this section, we consider a number of accounts of this process.

Speakers' gestures convey meaning but, importantly, they do so using a different representational format from speech. Gesture conveys meaning globally, relying on visual and mimetic imagery, whereas speech conveys meaning discretely, relying on codified words and grammatical devices (McNeill 1992). According to McNeill's (1992, 2005; McNeill & Duncan 2000) growth point theory, the internal core or growth point of an utterance contains both the global-synthetic image carried by gesture and the linear-segmented hierarchical linguistic structure carried by speech. Moreover, the visuo-spatial and linguistic aspects of an utterance cannot be separated—gesture and speech form a single integrated system.

Building on these ideas, the information-packaging hypothesis (Kita 2000) holds that producing gestures helps speakers organize and package visuo-spatial information into units that are compatible with the linear, sequential format of speech. The visuo-spatial representations that underlie gestures offer possibilities for organizing information that differ from the more analytic representations that underlie speech. When describing complex spatial information (such as a set of actions or an array of objects), there are many possible ways in which the information can be broken down into units and sequenced. According to the information-packaging hypothesis, gestures, which are individual actions in space, help speakers to select and organize the visuo-spatial information into units that are appropriate for verbalization. For example, in describing the layout of furniture in a room, a speaker might produce a gesture in which her two hands represent a couch and a chair as they are positioned in the room,

and this might help in formulating the utterance, "The couch and the chair are facing one another."

The most straightforward way to test the information-packaging hypothesis would be to manipulate gesture and observe the impact of that manipulation on how speech is packaged. At the moment, the evidence for the theory is more indirect—studies have manipulated the demands of packaging visuo-spatial information and shown that this manipulation has an effect on gesture production. In tasks where it is more challenging to package information into linguistic form, speakers produce more gestures, even when other factors are controlled. For example, Hostetter et al. (2007) asked participants to describe arrays of dots in terms of the geometric shapes that connected those dots (e.g., "The top three dots form a triangle, and the base of that triangle is the top of a square with dots at each corner"). For some participants, the shapes were drawn in the dot arrays, so packaging the information into units was easy; for other participants, the shapes were not provided, so participants had to decide on their own how to group the dots into shapes. In the second case, packaging the information into units for speaking was more challenging. As predicted by the information-packaging hypothesis, participants in this latter group produced more gestures when describing the arrays.

Whether or not we gesture is also influenced by the ease with which we can access words, as proposed in Krauss's (1998, Krauss et al. 2000) lexical gesture process model. According to this theory, gestures cross-modally prime lexical items, increasing their activation and making them easier to access. For example, if a speaker produces a circular gesture as he starts to say, "The ball rolled down the hill," the gesture will increase activation of the lexical item "roll," making it easier for the speaker to access that word. As evidence, when lexical access is made more difficult, speakers gesture at higher rates (Chawla & Krauss 1994, Morsella & Krauss 2004). Conversely, when

Global-synthetic: a representation that is not divided into parts but rather captures the whole of the referent

Linear-segmented: a representation that is composed of discrete parts produced in a sequence

gesture is prohibited, speakers become more dysfluent (Rauscher et al. 1996).

The interface model proposed by Kita & Özyürek (2003) extends these theories, arguing that gestures are planned by an action generator and verbal utterances by a message generator. According to this view, although speech and gesture are generated by separate systems, those systems communicate bidirectionally and interact as utterances are conceptualized and formulated. Gestures are thus shaped by the linguistic possibilities and constraints provided by the language they accompany. Evidence for this view comes from cross-linguistic findings showing that the gestures that speakers produce are shaped by the syntactic structures that underlie their language. For example, in English, the manner and path of a motion event are expressed in the same clause (run down), with manner in the verb and path in a satellite to the verb, as in “The child runs (manner) down (path) the street.” In contrast, in Turkish, manner and path are expressed in separate clauses (run and descend), with path in one verb and manner in another, as in “*Cocuk kosarak tepeden asagi indi*” = child as running (manner) descended (path) the hill. When English speakers produce gestures for manner and path, they typically conflate the two into a single gesture (an inverted V with wiggling fingers produced while moving the hand in a downward trajectory = run + down), paralleling the single-clause structure of their speech. Turkish speakers, in contrast, typically produce separate gestures for manner and path (a palm moved downward = down, followed by an inverted V with wiggling fingers in place = run), paralleling the two-clause structure of their speech (Özyürek et al. 2008). The particular gestures we produce are shaped by the words we speak.

An alternative view of the mechanism underlying gesture production is the gesture-as-simulated-action framework (Hostetter & Alibali 2008, 2010), which holds that speakers naturally activate simulations of actions and perceptual states when they produce speech. These simulations activate areas of motor and premotor cortex responsible for producing

movements. If the level of motor activation exceeds a preset threshold (which is influenced by individual, social, and contextual factors), then the speaker produces overt motor movements, which we recognize as gestures. For example, according to this view, in speaking about a child running down a hill, a speaker forms a mental simulation of the scene that includes action and perceptual components. This simulation will activate corresponding motor and premotor areas, and if activation in those areas exceeds the speaker’s gesture threshold, the speaker will produce a gesture. In support of this view, a number of studies have found that gesture rates increase when action and perceptual simulations are activated (Hostetter & Alibali 2010, Sassenberg & Van Der Meer 2010). Within this framework, linguistic factors may also influence the form of the gestures, as long as they influence the nature of speakers’ simulations. For example, if linguistic factors affect the way the speaker simulates a child running down a hill, they will also shape the form of the gestures that the speaker uses to describe that event because gesture and speech are expressions of the same simulation. Thus, according to the gesture-as-simulated-action framework, speaking involves simulations of perception and action, and gestures arise as a natural consequence of these simulations.

Gesture Comprehension and Its Role in Understanding Language

Although some argue that gesture plays little role in language comprehension (Krauss et al. 1995, 1996), there is a great deal of evidence that gesture can have an impact on language comprehension. Consider a speaker who says, “The man was wearing a hat,” while moving her hand as though grasping the bill of a baseball cap. This gesture could help listeners understand that the man was wearing a hat, and it might even encourage them to infer that the hat was a baseball cap. Both observational and experimental studies support these claims.

A recent quantitative meta-analysis that included 63 separate samples found that gestures

foster comprehension in listeners (Hostetter 2011). The overall effect size was moderate, and the size of the beneficial effect depended on several factors, including the topic of the gestures, their semantic overlap with speech, and the age of the listeners. Across studies, gestures about topics involving movement (e.g., how to make pottery; Sueyoshi & Hardison 2005) yielded greater benefits for listeners' comprehension than gestures about abstract topics (e.g., the taste of tea; Krauss et al. 1995). In addition, gestures that conveyed task-relevant information not expressed in speech (e.g., a gesture depicting width while saying "this cup is bigger") played a greater role in comprehension than gestures that conveyed information that was also expressed in speech (e.g., a gesture depicting width while saying "this cup is wider"). Finally, children showed greater benefits from gesture than did older listeners.

In this section, we review two types of evidence arguing that gesture has an effect on language comprehension: (a) evidence that speakers' gestures affect listeners' comprehension of speech and (b) evidence that speakers' gestures communicate information that is not expressed in speech. We conclude by considering whether there is evidence that speakers intend their gestures to be communicative.

Do speakers' gestures affect listeners' comprehension of speech? Under ordinary circumstances, listeners comprehend speech with ease. However, if speech is difficult to comprehend because it is unclear, ambiguous, or difficult relative to the listeners' skills, gesture can provide a second channel that makes successful comprehension more likely.

Many studies have investigated whether gestures influence listeners' comprehension of speech. These include studies using video clips as stimuli (e.g., Kelly & Church 1997) and studies in which listeners view or participate in "live" interactions (e.g., Goldin-Meadow et al. 1999, Goldin-Meadow & Sandhofer 1999, Holler et al. 2009). Across studies, researchers have used a variety of outcome measures to evaluate comprehension. In some studies, par-

ticipants are asked to answer questions about the speech they heard (e.g., Kelly & Church 1998); in others, they are asked to restate or reiterate that speech (e.g., Alibali et al. 1997). In still other studies, participants' spontaneous uptake of information from others' speech was assessed, either in their next speaking turn (Goldin-Meadow et al. 1999) or in their behavioral responses (McNeil et al. 2000).

Across studies, there is strong evidence that gestures affect listeners' comprehension of speech. When gestures express information that is redundant with speech, they contribute to successful comprehension (Goldin-Meadow et al. 1999, McNeil et al. 2000). When gestures express information that is not expressed in speech, they can detract from listeners' direct uptake of the information in speech (e.g., Goldin-Meadow & Sandhofer 1999), but they often communicate important information in their own right, an issue we address in the next section.

Does gesture communicate information on its own? When gesture conveys the same information as speech, it appears to help listeners pick up that information. But what happens when gesture conveys different information from speech? In the earlier hypothetical example in which the speaker said, "The man was wearing a hat," while moving her hand as if grasping the bill of a baseball cap, the speaker expressed information about the type of hat (a baseball cap—not a cowboy hat, a stocking cap, or a sombrero) uniquely in gesture. Do listeners detect information that speakers express uniquely in gesture? They do. For example, Kelly & Church (1998) presented video clips of children explaining their judgments of Piagetian conservation tasks and asked participants to respond to yes/no questions about the reasoning that the children expressed. A child in one video clip mentioned the height of a container in speech, but indicated the width of the container in gesture. When probed, observers often credited this child with reasoning about both the height and the width of the container. Other studies have also shown

Deictic gesture:

pointing at an object or holding the object up to draw attention to it

Iconic gesture:

hand movements produced along with speech that display attribute or action information

that listeners often incorporate the information conveyed uniquely in gesture into their own speech (Goldin-Meadow et al. 1992, McNeill et al. 1994). Thus, observers credit speakers with saying things that they express uniquely in gesture.

Are gestures intended to be communicative? It is clear that gestures contribute to listeners' comprehension. But do speakers intend for their gestures to communicate or are gestures' communicative effects merely an epiphenomenon of the gestures that speakers produce in the effort of speech production?

Several lines of evidence suggest that speakers do intend at least some of their gestures to be communicative. First, speakers gesture more when their listeners can see those gestures than when visibility between speaker and listener is blocked (Alibali et al. 2001, Mol et al. 2011). Second, when speakers repeat a message to different listeners, their gesture rates do not decline as they might if gestures were produced solely to help with speech production (Jacobs & Garnham 2007). Third, when speakers are explicitly asked to communicate specific information to their listeners, they sometimes express some of that information uniquely in gesture and not in speech. For example, Melinger & Levelt (2004) explicitly directed speakers to communicate specific spatial information about a task to their addressees. Speakers frequently expressed this requested information in gesture and not in speech, suggesting that at least these gestures were intended to be communicative.

To summarize thus far, gesture plays a role in both language production and comprehension. One area that has received very little attention is individual differences (but see Bergmann & Kopp 2010, Hostetter & Alibali 2007)—are there differences in the rate at which people gesture when they speak or in the reliance people put on gesture when they listen to the speech of others? We know little about what accounts for individual differences in gesture, or even how consistent those differences are across tasks and conversational partners. This is an area of re-

search in gesture studies that is ripe for future examination.

GESTURE'S ROLE IN LANGUAGE LEARNING AND BEYOND

Mature speakers of a language routinely use gesture when they talk, but so do young children just learning to talk. In fact, most children use gesture prior to speaking, and these gestures not only precede linguistic progress, but they also play a role in bringing that progress about.

Gesture's Role in the Early Stages of Language Learning

Gesture precedes and predicts changes in language. Children typically begin to gesture between 8 and 12 months (Bates 1976, Bates et al. 1979). They first use deictic gestures, whose meaning is given entirely by context and not by their form. For example, a child can hold up or point at an object to draw an adult's attention to it months before the child produces her first word (Iverson & Goldin-Meadow 2005). Pointing gestures function like context-sensitive pronouns ("this" or "that") in that an adult has to follow the gesture's trajectory to its target in order to figure out which object the child is indicating. In addition to deictic gestures, children produce conventional gestures common to their cultures (Guidetti 2002). For example, in the United States, children may produce a side-to-side headshake to mean "no" or a finger held over the lips to mean "shush." Children also produce iconic gestures, although initially the number tends to be quite small and varies across children (Acredolo & Goodwyn 1988). For example, a child might open and close her mouth to represent a fish or flap her hands at her sides to represent a bird (Iverson et al. 1994). Unlike pointing gestures, the form of an iconic gesture captures aspects of its intended referent—its meaning is consequently less dependent on context. These gestures therefore have the potential to function like words; according to Goodwyn & Acredolo

(1998, p. 70), they do just that and can be used to express an idea that the child cannot yet express in speech.¹

Even though they treat their early gestures like words in some respects, children rarely combine gestures with other gestures, and if they do, the phase is short lived (Goldin-Meadow & Morford 1985). But children do frequently combine their gestures with words, and they produce these combinations well before they combine words with words. Because gesture and speech convey meaning differently, it is rare for the two modalities to contribute identical information to a message. Even simple pointing gestures are not completely redundant with speech. For example, when a child says “bottle” while pointing at the bottle, the word labels and thus classifies, but does not locate, the object. The point, in contrast, indicates where the object is, but not what it is. When produced together, point and word work together to more richly specify the same object. Children’s earliest gesture-speech combinations are of this type—gesture conveys information that further specifies the information conveyed in speech; for example, pointing at a box while saying “box” (Capirci et al. 1996, de Laguna 1927, Greenfield & Smith 1976, Guillaume 1927, Leopold 1949).

But gesture can also convey information that overlaps very little, if at all, with the information conveyed in the word it accompanies. A point, for example, can indicate an object that is not referred to in speech—the child says “bottle” while pointing at the baby. In this case, word and gesture together convey a simple proposition—“the bottle is the baby’s”—that neither modality conveys on its own (Goldin-Meadow & Morford 1985; Greenfield & Smith 1976; Masur 1982, 1983; Morford & Goldin-Meadow 1992; Zinober & Martlew 1985).

¹Two other types of gestures found in adult repertoires—the simple rhythmic beat gesture that patterns with discourse and does not convey semantic content, and the metaphorical gesture that represents abstract ideas rather than concrete ones—are not produced by children until much later in development (McNeill 1992).

The types of semantic relations conveyed in these gesture-speech combinations change over time and presage changes in children’s speech (Özçaliskan & Goldin-Meadow 2005). For example, children produce constructions containing an argument and a predicate in gesture + speech (“you” + HIT gesture) at 18 months but do not produce these constructions in speech alone (“me touch”) until 22 months.

Children thus use gesture to communicate before they use words. But do these gestures merely precede language development or are they fundamentally tied to it? If gesture is integral to language learning, changes in gesture should not only predate, but also predict, changes in language. And they do. With respect to words, we can predict which lexical items will enter a child’s verbal vocabulary by looking at the objects that child indicated in gesture several months earlier (Iverson & Goldin-Meadow 2005). With respect to sentences, we can predict when a child will produce her first two-word utterance by looking at the age at which she first produced combinations in which gesture conveys one idea and speech another (e.g., point at bird + “nap”; Goldin-Meadow & Butcher 2003, Iverson et al. 2008, Iverson & Goldin-Meadow 2005).

Gesture can cause linguistic change. There are (at least) two ways in which children’s own gestures can change what they know about language. First, as we discussed above, gesture gives young children the opportunity to express ideas that they are not yet able to express in speech. Parents and other listeners may attend to those gestures and translate them into speech, thus providing children with timely input about how to express particular ideas in their language. Under this scenario, gesture plays a role in the process of change by shaping children’s learning environments. Mothers do, in fact, respond to the gestures their children produce (Golinkoff 1986, Masur 1982), often translating gestures that children produce without speech into words (Goldin-Meadow et al. 2007a). These mother translations have been found to have an effect on language learning.

With respect to word learning, when mothers translate the gestures that their children produce into words, those words are more likely to quickly become part of the child's vocabulary than are words for gestures that mothers do not translate. With respect to sentence learning, children whose mothers frequently translate their child's gestures into speech tend to be first to produce two-word utterances (Goldin-Meadow et al. 2007a).

Second, gesture could play a causal role in language learning by providing children with the opportunity to practice ideas and communicative devices that underlie the words and constructions that they are not yet able to express in speech. Repeated practice could then pave the way for later acquisition. Under this scenario, gesture plays a role in the process of change by affecting the learners themselves. Evidence for this hypothesis comes from the fact that child gesture at 14 months is an excellent predictor of child vocabulary at 42 months, often better than other predictors (e.g., family income, parent speech, and even child speech at 14 months; Rowe & Goldin-Meadow 2009, Rowe et al. 2008). However, to convincingly demonstrate that child gesture plays a causal role in word learning, we would need to randomly select children and manipulate their gestures, encouraging some to gesture and discouraging others. If the act of gesturing itself contributes to progress in language development (as it does in other domains; see *Gesture Can Cause Knowledge Change* section below), children who are encouraged to gesture should have larger vocabularies than children who are discouraged from gesturing.

The gestures that others produce may also play a causal role in language learning. By 12 months, children can understand the gestures that other people produce. For example, they can follow an adult's pointing gesture to a target object (Butterworth & Grover 1988, Carpenter et al. 1998, Murphy & Messer 1977). Moreover, parents gesture frequently when they interact with their children, and the majority of these gestures co-occur with speech (Acredolo & Goodwyn 1988, Greenfield &

Smith 1976, Shatz 1982). Parent gesture could facilitate the child's comprehension, and eventual acquisition, of new words simply by providing nonverbal support for understanding speech (see Zukow-Goldring 1996).

However, it is often hard to tell whether parent gesture has an impact on child language learning above and beyond parent speech. For example, Iverson et al. (1999) and Pan et al. (2005) both found a relation between parent gesture and later child language, but the relation disappeared when parent speech was taken into account. The best way to convincingly test this hypothesis is to manipulate parent gesture and observe the effects on child language. Acredolo & Goodwyn (1988) instructed parents to use symbolic gestures (now called baby signs; Acredolo & Goodwyn 2002) in addition to words when talking to their children. They found that these children showed greater gains in vocabulary than children whose parents were encouraged to use only words or were not trained at all. But the children whose parents used gesture also used more of their own gestures. The vocabulary gains may thus have been mediated by child gesture.

Previous work has, in fact, found a link between parent gesture and child gesture—parents who gesture a great deal have children who gesture a great deal (Iverson et al. 1999, Namy et al. 2000, Rowe 2000). Moreover, parent gesture at 14 months predicts child gesture at 14 months, which, in turn, predicts child receptive vocabulary at 42 months (Rowe & Goldin-Meadow 2009). Importantly, parent gesture at 14 months does not directly predict child vocabulary at 42 months (Rowe et al. 2008), suggesting that parent gesture affects later child vocabulary through child gesture—parents who gesture more have children who gesture more who, in turn, go on to develop relatively large receptive vocabularies in speech.

To summarize thus far, gesture appears to play a role in learning when the task to be learned is language itself. When gesture is produced by children who are learning language, it often substitutes for a word that the child has not yet acquired. As we will discuss in the next

section, gesture continues throughout development to convey ideas that are not expressed in speech, but often those ideas cannot easily be translated into a single word (McNeill 1992). Thus, once children have become proficient language users, we should see a change in the kinds of ideas that gesture conveys. Future studies are needed to determine when this transition takes place.

Once Language Has Been Mastered: Gesture's Role in Learning Other Domains

Gesture thus seems to offer children a helping hand as they learn language. Does gesture play a comparable role in other domains? We turn next to this question.

Gesture reveals understanding not found in speech. When children explain their understanding of concepts and problem-solving procedures, they often express some aspects of their knowledge in gestures and not in speech. Consider a six-year-old child explaining a Piagetian conservation of matter task, in which two rows of checkers contain the same number; the checkers in one row are spread out and the child is asked whether the two rows continue to have the same number of checkers. Children who do not yet understand number conservation believe that the number of checkers in the transformed row has changed. **Figure 1a** displays a nonconserving child who says the number is different “because you spreaded them out” and conveys the same information in her gestures (she produces a spreading-out motion over the transformed row). In contrast, **Figure 1b,c** displays another nonconserving child who also focuses on the movements of the experimenter in his speech—he says the number is different “because you moved them.” However, in his gestures, he indicates that the checkers in one row can be paired with the checkers in the second row; that is, he has focused on the one-to-one correspondence between the rows. This child has expressed information about the task in gestures that he

did not express at all in his speech. Responses of this sort have been called gesture-speech mismatches (Church & Goldin-Meadow 1986).

People express aspects of their knowledge in gesture on a wide range of cognitive tasks, including mathematical equations (e.g., Perry et al. 1988), balance tasks (e.g., Pine et al. 2004), logical puzzles (e.g., the Tower of Hanoi; Garber & Goldin-Meadow 2002), science explanations (Roth 2002), and even moral reasoning (Church et al. 1995). In all of these domains, people sometimes express information in gesture that they do not express in the accompanying speech. Thus, across a wide range of cognitive domains, gesture reveals information about people's reasoning and problem solving that is not found in their speech.

Gesture-speech mismatches may occur when children explore aspects of the task stimuli in gesture but do not ultimately express all of those aspects in speech. In the example presented in **Figure 1b,c**, the child uses gesture to explore the one-to-one-correspondence between the checkers in the two rows, but he does not ultimately express this aspect of the task in his speech.

The mismatch between gesture and speech presages knowledge change. Gesture-speech mismatches are of interest because they provide insight into aspects of learners' knowledge that they do not express in speech. But even more important, mismatches are a good index of the stability of a learner's knowledge. Several studies across a variety of domains have shown that children who produce gesture-speech mismatches when explaining a concept are in a state of transitional knowledge with respect to that concept. For example, in the domain of Piagetian conservation, Church & Goldin-Meadow (1986) found that, among partial conservers (i.e., children who conserved on some tasks and not on others), those who produced a majority of mismatches in their conservation explanations prior to instruction were more likely to profit from instruction about conservation than were those who produced few mismatches. Thus, frequent

Conservation of matter:

understanding that quantity does not change when it is merely rearranged

Gesture-speech mismatch:

an utterance in which the information conveyed in gesture is different from the information conveyed in the speech that it accompanies

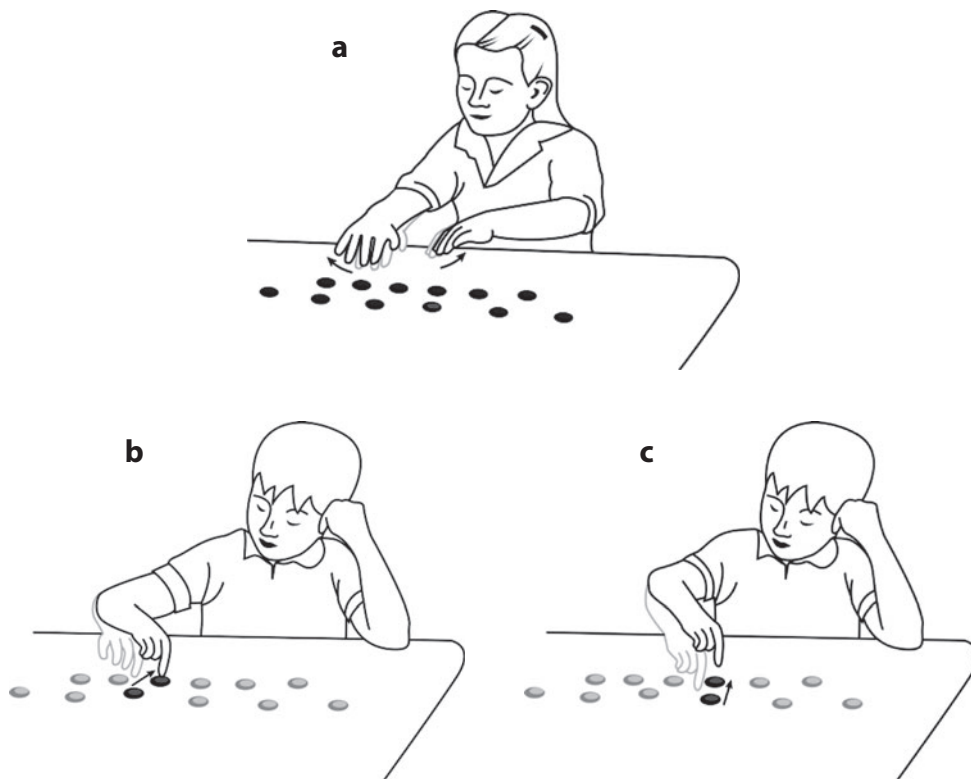


Figure 1

Examples of children gesturing while giving explanations for their nonconserving judgments on a number conservation task. In the top picture (*a*), the child says, “you spreaded them out,” while producing a spreading motion with her hands, thus producing a gesture-speech match. In the bottom pictures (*b,c*), the child says, “you moved them,” again focusing on the experimenter’s movements in speech, but he produces pointing gestures that align the checkers in one row with the checkers in the other row (one-to-one correspondence), thus producing a gesture-speech mismatch.

mismatches between speech and gesture in children’s task explanations at pretest indexed their readiness to benefit from instruction. Similar findings have been documented in children learning about mathematical equations such as $3 + 4 + 5 = 3 + _$ (Perry et al. 1988), in children solving balance problems (Pine et al. 2004), and in adults learning about stereoisomers in organic chemistry (Ping et al. 2012).

Gesture-speech mismatch thus reflects readiness to learn—and does so better than other possible indices of learning that rely on the verbal channel alone. Church (1999) compared three indices that can be used to

predict children’s readiness to learn from a conservation lesson: number of pretest responses containing a gesture-speech mismatch (i.e., two different strategies, one in speech and one in gesture), number of pretest responses containing more than one strategy in speech (i.e., two different strategies, both in speech), and total number of different strategies conveyed in speech across the entire pretest. Each of these indices individually predicted learning from the lesson, but when all three were included in the same model, the only significant predictor was gesture-speech mismatch.

Gesture-speech mismatches also index knowledge transition in another sense: The

state in which children frequently produce mismatches is both preceded and followed by a state in which they seldom produce mismatches. In a microlongitudinal study, Alibali & Goldin-Meadow (1993) tracked the relationship between gesture and speech in children's explanations over a series of problems as the children learned to solve mathematical equations, such as $3 + 4 + 5 = 3 + _$. Among children who produced gestures on the task, the large majority of children traversed all or part of the following path: (a) Children began in a state in which they predominantly produced gesture-speech match responses, expressing a single, incorrect strategy for solving the problems conveyed in both gesture and speech. (b) They then progressed to a state in which they produced gesture-speech mismatches, expressing more than one strategy, one in gesture and the other in speech. (c) Finally, they reached a state in which they produced gesture-speech match responses, now expressing a single, correct strategy conveyed in both gesture and speech. Thus, the state in which children frequently produce gesture-speech mismatches is also transitional in the sense that it is both preceded and followed by a more stable state.

Gesture can cause knowledge change. Gesture can provide information about the content and stability of children's knowledge. But can gesture do more? As in language learning, gesture might play a causal role in the process of knowledge change. There are (at least) two classes of mechanisms by which gestures could play a causal role in bringing about knowledge change: social mechanisms by which learners' gestures convey information about their knowledge states to listeners who, in turn, alter the input they provide to the learners, and cognitive mechanisms by which learners' own gestures alter the state of their knowledge. We consider each class of mechanisms in turn.

Social mechanisms by which gesture can cause change. Gesture is implicated in social mechanisms of knowledge change. According to these mechanisms, learners' gestures convey infor-

mation about their cognitive states to listeners (teachers, parents, or peers), and those listeners then use this information to guide their ongoing interactions with the learners. Learners' gestures can provide information about the leading edge of their knowledge, information that could be used to scaffold their developing understanding. Learners thus have the potential to influence the input they receive just by moving their hands. For the social construction of knowledge to occur in this way, listeners must grasp the information that learners express in their gestures, and they must also change their responses to those learners as a function of the information. Evidence supports both of these steps.

As reviewed in the section on gesture's role in language comprehension, there is evidence that listeners detect and interpret the information that speakers express solely in their gestures on a variety of tasks, for example, on Piagetian conservation problems (Goldin-Meadow et al. 1992; Kelly & Church 1997, 1998) and mathematical equations (Alibali et al. 1997). Moreover, there is evidence that listeners can detect gestured information not only when viewing speakers on video, but also when interacting with live speakers in real time (Goldin-Meadow & Sandhofer 1999).

As one example, Alibali and colleagues (1997) presented clips of children explaining mathematics problems to two groups of adults—teachers and college students—and asked the adults to describe each child's reasoning about the problems. Both teachers and college students detected the information that children expressed in their gestures. In some of the clips, the child expressed a strategy for solving the problems solely in gesture. For example, one boy explained his incorrect solution (he put 18 in the blank) to the problem $5 + 6 + 7 = _ + 7$ by saying that he added the numbers on the left side of the equation. In gesture; however, he pointed to the 5 and the 6—the two numbers that should be added to yield the correct solution of 11. In reacting to this clip, one teacher said, "What I'm picking up now is [the child's] inability to realize that these (5 and

6) are meant to represent the same number. . . . There isn't a connection being made by the fact that the 7 on this (left) side of the equal sign is supposed to also be the same as this 7 on this (right) side of the equal sign, which would, you know, once you made that connection it should be fairly clear that the 5 and 6 belong in the box." It seems likely that the teacher's reaction was prompted by the child's gestures. Indeed, the teachers were more likely to mention a strategy when the target child expressed that strategy solely in gesture than when the target child did not express the strategy in either gesture or speech.

Communication partners can thus glean information from a learner's gestures. But do they use this information to guide their interactions with the learner? If the teacher in the preceding example were asked to instruct the child she viewed in the video, she might point out the two 7's and suggest that the child cancel the like addends and then group and add the remaining numbers. In this way, the teacher would be tailoring her instruction to the child's knowledge state, and instruction that is targeted to a child's knowledge state might be particularly helpful in promoting learning in the child.

Teachers have been found to alter their input to children on the basis of the children's gestures. Goldin-Meadow & Singer (2003) asked teachers to instruct children in one-on-one tutorials on mathematical equations; they asked whether the teachers' instruction varied as a function of their pupils' gestures. They found that the teachers offered more different types of problem-solving strategies to children who produced gesture-speech mismatches, and also produced more mismatches of their own (i.e., typically a correct strategy in speech and a different correct strategy in gesture), when instructing children who produced mismatches than when instructing children who produced matches. Importantly, including mismatches of this sort in instruction greatly increases the likelihood that children will profit from that instruction (Singer & Goldin-Meadow 2005). Children can thus have an active hand in shaping their own instruction.

Cognitive mechanisms by which gesture can cause change. There is growing evidence that producing gestures can alter the gesturer's cognitive state. If this is the case, then a learner's gestures will not only reflect the process of cognitive change but also cause that change. A number of specific claims regarding how gesturing might cause cognitive change have been made.

First, gestures may manifest implicit knowledge that a learner has about a concept or problem. When learners express this implicit knowledge and express other more explicit knowledge at the same time, the simultaneous activation of these ideas may destabilize their knowledge, making them more receptive to instructional input and more likely to alter their problem-solving strategies. In support of this view, Broaders and colleagues (2007) told some children to gesture and others not to gesture as they solved a series of mathematical equations. When required to gesture, many children expressed problem-solving strategies in gesture that they had not previously expressed in either speech or gesture. When later given instruction in the problems, it was the children who had been told to gesture and expressed novel information in those gestures who were particularly likely to learn mathematical equivalence.

Second, gesturing could help learners manage how much cognitive effort they expend. Goldin-Meadow et al. (2001; see also Ping & Goldin-Meadow 2010, Wagner et al. 2004) found that speakers who gestured when explaining how they solved a series of math problems while at the same time trying to remember an unrelated list of items had better recall than speakers who did not gesture. This effect holds even when speakers are told when to gesture and told when not to gesture (Cook et al. 2012). If gesturing does serve to reduce a learner's effort, that saved effort could be put toward other facets of the problem and thus facilitate learning.

Third, gesturing could serve to highlight perceptual or motor information in a learner's representations of a problem, making that information more likely to be engaged when

solving the problem. In line with this view, Alibali & Kita (2010) found that children asked to solve a series of Piagetian conservation tasks were more likely to express information about the perceptual state of the task objects when they were allowed to gesture than when they were not allowed to gesture. Similarly, in a study of adult learners asked to predict how a gear in an array of gears would move if the first gear were rotated in a particular direction, Alibali et al. (2011) found that learners who were allowed to gesture were more likely to persist in using a perceptual-motor strategy to solve the problems (i.e., modeling the movements of each individual gear) and less likely to shift to a more abstract strategy (i.e., predicting the movement of the gear based on whether the total number of gears was even or odd).

As another example, Beilock & Goldin-Meadow (2010) demonstrated that gesturing can introduce motor information into a speaker's mental representations of a problem. They used two versions of the Tower of Hanoi task, a puzzle in which four disks must be moved from one of three pegs to another peg; only one disk can be moved at a time and a bigger disk can never be placed on top of a smaller disk. In one version, the heaviest disk was also the largest disk; in the other, the heaviest disk was the smallest disk. Importantly, the heaviest disk could not be lifted with one hand. Participants solved the problem twice. Some participants used the largest = heaviest version for both trials (the No Switch group); others used the largest = heaviest version on the first trial and the smallest = heaviest version on the second trial (the Switch group). In between the two trials, participants were asked to explain how they solved the problem and to gesture during their explanation. Participants who used one-handed gestures when describing the smallest disk during their explanation of the first trial performed worse on the second trial than participants who used two-handed gestures to describe the smallest disk—but only in the Switch group (recall that the smallest disk could no longer be lifted with one hand after the disks were switched). Participants in the No Switch group improved

on the task no matter which gestures they produced, as did participants who were not asked to explain their reasoning and thus produced no gestures at all. The participants never mentioned weight in their talk. But weight information is an inherent part of gesturing on this task—one has to use either one hand (light disk) or two (heavy disk) when gesturing. When the participants' gestures highlighted weight information that did not align with the actual movement needed to solve the problem, subsequent performance suffered. Gesturing thus introduced action information into the participants' problem representations, and this information affected their later problem solving.

It is likely that both cognitive and social mechanisms operate when gesture is involved in bringing about change (Goldin-Meadow 2003a). For example, Streeck (2009) argues that gesturing does not just reflect thought, but it is part of the cognitive process that accomplishes a task, and in this sense, is itself thought. Moreover, because gesture is an observable and external aspect of the cognitive process, it puts thought in the public domain and thus opens the learner to social mechanisms (see also Alac & Hutchins 2004, Goodwin 2007).

GESTURE'S ROLE IN CREATING LANGUAGE

We have seen that when gesture is produced along with speech, it provides a second window onto the speaker's thoughts, offering insight into those thoughts that cannot be found in speech and predicting (perhaps even contributing to) cognitive change. The form that gesture assumes when it accompanies speech is imagistic and continuous, complementing the segmented and combinatorial form that characterizes speech. But what happens when the manual modality is called upon to fulfill, on its own, all of the functions of language? Interestingly, when the manual modality takes over the functions of language, as in sign languages of the deaf, it also takes over its segmented and combinatorial form.

Sign Language: Codified Manual Language Systems Transmitted Across Generations

Sign languages of the deaf are autonomous languages that do not depend on the spoken language of the surrounding hearing community. For example, American Sign Language (ASL) is structured very differently from British Sign Language, despite the fact that English is the spoken language that surrounds both sign communities.

Even though sign languages are processed by the hand and eye rather than the mouth and ear, they have the defining properties of segmentation and combination that characterize all spoken language systems (Klima & Bellugi 1979, Sandler & Lillo-Martin 2006). Sign languages are structured at the sentence level (syntactic structure), at the sign level (morphological structure), and at the subsign level and thus have meaningless elements akin to phonemes (phonological structure). Just like words in spoken languages (but unlike the gestures that accompany speech; Goldin-Meadow et al. 1996), signs combine to create larger wholes (sentences) that are typically characterized by a basic order, for example, SVO (Subject-Verb-Object) in ASL (Chen Pichler 2008) and SOV in Sign Language of the Netherlands (Coerts 2000). Moreover, the signs that comprise the sentences are themselves composed of meaningful components (morphemes; Klima & Bellugi 1979).

Although many of the signs in a language like ASL are iconic (i.e., the form of the sign is transparently related to its referent), iconicity characterizes only a small portion of the signs and structures in any conventional sign language. Moreover, sign languages do not always take advantage of the iconic potential that the manual modality offers. For example, although it would be physically easy to indicate the manner by which a skateboarder moves in a circle within the sign that conveys the path, to be grammatically correct the ASL signer must produce separate, serially linked signs, one for the manner and a separate one for the

path (Supalla 1990). As another example, the sign for “slow” in ASL is made by moving one hand across the back of the other hand. When the sign is modified to be “very slow,” it is made more rapidly since this is the particular modification of movement associated with an intensification meaning in ASL (Klima & Bellugi 1979). Thus, modifying the meaning of a sign can reduce its iconicity.

Moreover, the iconicity found in a sign language does not appear to play a significant role in the way the language is processed or learned. For example, young children are just as likely to learn a sign whose form does not resemble its referent as a sign whose form is an iconic depiction of the referent (Bonvillian et al. 1983). Similarly, young sign learners find morphologically complex constructions difficult to learn even if they are iconic. Moving the sign “give” from the chest toward the listener would seem to be an iconically transparent way of expressing “I give to you” and thus ought to be an early acquisition if children are paying attention to iconicity. However, the sign turns out to be a relatively late acquisition, presumably because the sign is marked for both the agent (I) and the recipient (you) and is thus morphologically complex (Meier 1987).

Interestingly, the segmentation and combination that characterizes established languages, signed or spoken, is also found in newly emerging sign languages, as we discuss in the next section.

Emerging Sign Systems

Deaf children born to deaf parents who are exposed to a conventional sign language learn that language as naturally, and following the same major milestones, as hearing children learning a spoken language from their hearing parents (Lillo-Martin 1999, Newport & Meier 1985). But 90% of deaf children are born to hearing parents who are not likely to know a conventional sign language (Hoffmeister & Wilbur 1980). These hearing parents very often prefer that their deaf child learn a spoken rather than a signed language. They thus choose to educate

the child using an oral method of instruction, instruction that focuses on lip-reading and discourages the use of sign language and gesture. Unfortunately, it is extremely difficult for a profoundly deaf child to learn a spoken language, even when that child is given intensive oral education (Mayberry 1992). Under these circumstances, one might expect that a child would not communicate at all. But that is not what happens—deaf children who are unable to use the spoken language input that surrounds them and have not been exposed to sign language do communicate with the hearing individuals in their households, and they use gesture to do so.

The gestures that deaf children in these circumstances develop are called homesigns. Interestingly, homesigns are characterized by segmentation and combination, as well as many other properties found in natural languages (Goldin-Meadow 2003b). For example, homesigners' gestures form a lexicon, and these lexical items are composed of morphemes and thus form a system at the word level (Goldin-Meadow et al. 2007b). Moreover, the lexical items combine to form syntactically structured strings and thus form a system at the sentence level (Feldman et al. 1978, Goldin-Meadow & Mylander 1998), with negative and question sentence modulators (Franklin et al. 2011), grammatical categories (Goldin-Meadow et al. 1994), and hierarchical structure built around the noun (Hunsicker & Goldin-Meadow 2012). Importantly, homesigners use their gestures not only to make requests of others, but also to comment on the present and nonpresent (Morford & Goldin-Meadow 1997), to make generic statements about classes of objects (Goldin-Meadow et al. 2005), to tell stories about real and imagined events (Morford 1995, Phillips et al. 2001), to talk to themselves, and to talk about language (Goldin-Meadow 2003b)—that is, to serve typical functions that all languages serve, signed or spoken.

But homesign does not exhibit all of the properties found in natural language. We can explore the conditions under which homesign takes on more and more linguistic properties to

get a handle on factors that may have shaped human language. For example, deaf children rarely remain homesigners in countries such as the United States; they either learn a conventional sign language or receive cochlear implants and focus on spoken language. However, in Nicaragua, not only do some homesigners continue to use their gesture systems into adulthood, but in the late 1970s and early 1980s, rapidly expanding programs in special education brought together in great numbers deaf children and adolescents who were, at the time, homesigners (Kegl et al. 1999, Senghas 1995). As these children interacted on school buses and in the schoolyard, they converged on a common vocabulary of signs and ways to combine those signs into sentences, and a new language—Nicaraguan Sign Language (NSL)—was born.

NSL has continued to develop as new waves of children enter the community and learn to sign from older peers. NSL is not unique—other sign languages have originated in communal contexts and been passed from generation to generation. The Nicaraguan case is special because the originators of the language are still alive. We thus have in this first generation, taken together with subsequent generations and current-day homesigners (child and adult), a living historical record of a language as it develops through its earliest stages.

Analyses of adult homesign in Nicaragua have, in fact, uncovered linguistic structures that may turn out to go beyond the structures found in child homesign: the grammatical category subject (Coppola & Newport 2005), pointing devices representing locations versus nominals (Coppola & Senghas 2010), morphophonological finger complexity patterns (Brentari et al. 2012), and morphological devices that mark number (Coppola et al. 2012). By contrasting the linguistic systems constructed by child and adult homesigners, we can see the impact that growing older has on language creation.

In addition, by contrasting the linguistic systems constructed by adult homesigners in Nicaragua with the structures used by the first cohort of NSL signers, we can see the impact

that a community of users has on language. Having a group with whom they could communicate meant that the first cohort of signers were both producers and receivers of their linguistic system, a circumstance that could lead to a system with greater systematicity, but perhaps less complexity, as the group may need to adjust to the lowest common denominator (i.e., to the homesigner with the least complex system).

Finally, by contrasting the linguistic systems developed by the first and second cohorts of NSL signers (e.g., Senghas 2003), we can see the impact that passing a language through a new generation of learners has on language. Once learners are exposed to a system that has linguistic structure, the processes of language change may be identical to the processes studied in historical linguistics. One interesting question is whether the changes seen in NSL in its earliest stages are of the same type and magnitude as the changes that occur in mature languages over historical time.

Gestures Used by Hearing Adults When They Are Not Permitted to Speak

A defining feature of homesign is that it is not shared in the way that conventional communication systems are. Deaf homesigners produce gestures to communicate with the hearing individuals in their homes. But the hearing individuals, particularly hearing parents who are committed to teaching their children to talk and thus to oral education, use speech back. Although this speech is often accompanied by gesture (Flaherty & Goldin-Meadow 2010), as we discussed previously, the gestures that co-occur with speech form an integrated system with that speech and, in this sense, are not free to take on the properties of the deaf child's gestures. As a result, although hearing parents respond to their deaf child's gestures, they do not adopt the gestures themselves (nor do they typically acknowledge that the child even uses gesture to communicate). The parents produce cospeech gestures, not homesigns.

Not surprisingly, then, the structures found in child homesign cannot be traced back to the spontaneous gestures that hearing parents produce while talking to their children (Goldin-Meadow et al. 1994, Goldin-Meadow & Mylander 1983). Homesigners see the global and unsegmented gestures that their parents produce. But when gesturing themselves, they use gestures that are characterized by segmentation and combination. The gestures that hearing individuals produce when they talk therefore do not provide a model for the linguistic structures found in homesign.

Nevertheless, cospeech gestures could provide the raw materials (e.g., hand shapes, motions) for the linguistic constructions that homesigners build (see, for example, Goldin-Meadow et al. 2007b) and, as such, could contribute to the initial stages of an emerging sign language (see Senghas et al. 2004). Moreover, the disparity between cospeech gesture and homesign has important implications for language learning. To the extent that the properties of homesign differ from the properties of cospeech gesture, the deaf children themselves are likely to be imposing these particular structural properties on their communication systems. It is an intriguing, but as yet unanswered, question as to where the tendency to impose structure on homesign comes from.

We have seen that cospeech gestures do not assume the linguistic properties found in homesign. But what would happen if we were to ask hearing speakers to abandon speech and create a manual communication system on the spot? Would that system contain the linguistic properties found in homesign? Examining the gestures that hearing speakers produce when requested to communicate without speech allows us to explore the robustness of linguistic constructions created on-line in the manual modality.

Hearing gesturers asked to gesture without speaking are able to construct some properties of language with their hands. For example, the order of the gestures they construct on the spot indicates who does what to whom (Gershkoff-Stowe & Goldin-Meadow 2002,

Goldin-Meadow et al. 1996). However, hearing gesturers do not display other linguistic properties found in established sign languages and even in homesign. For example, they do not use consistent form-meaning pairings akin to morphemes (Singleton et al. 1993), nor do they use the same finger complexity patterns that established sign languages and homesign display (Brentari et al. 2012).

Interestingly, the gestures that hearing speakers construct on the spot without speech do not appear to be derived from their spoken language. When hearing speakers of different languages (English, Spanish, Chinese, Turkish) are asked to describe animated events using their hands and no speech, they abandon the order typical of their respective spoken languages and produce gestures that all conform to the same order—SOV (e.g., captain-pail-swings; Goldin-Meadow et al. 2008). This order has been found in some emerging sign languages (e.g., Al-Sayyid Bedouin Sign Language; Sandler et al. 2005). Moreover, the SOV order is also found when hearing speakers of the same four languages perform a noncommunicative, nongestural task (Goldin-Meadow et al. 2008). Recent work on English-, Turkish-, and Italian-language speakers has replicated the SOV order in hearing gesturers but finds that gesturers move away from this order when given a lexicon (either spoken or manual; Hall et al. 2010), when asked to describe reversible events involving two animates (girl pulled man; Meir et al. 2010), and when asked to describe more complex events (man tells child that girl catches fish; Langus & Nespors 2010). Studies of hearing gesturers give us the opportunity to manipulate conditions that have the potential to affect communication, and to then observe the effect of those conditions on the structure of the emerging language.

Do Signers Gesture?

We have seen that hearing speakers produce analog, imagistic signals in the manual modality (i.e., gesture) along with the segmented, discrete signals they produce in the oral modal-

ity (i.e., speech), and that these gestures serve a number of communicative and cognitive functions. The question we now ask is whether signers also produce gestures and, if so, whether those gestures serve the same functions as cospeech gesture.

Deaf signers have been found to gesture when they sign (Emmorey 1999). But do they produce mismatches, and do those mismatches predict learning? ASL-signing deaf children were asked to explain their solutions to the same math problems studied in hearing children (Perry et al. 1988) and were then given instruction in those problems in ASL. The deaf children produced gestures as often as the hearing children. Moreover, the deaf children who produced many gestures conveying different information from their signs (i.e., gesture-sign mismatches) were more likely to succeed after instruction than the deaf children who produced few (Goldin-Meadow et al. 2012).

These findings suggest not only that mismatch can occur within a single modality (hand alone), but also that within-modality mismatch can predict learning just as well as cross-modality mismatch (hand and mouth). Juxtaposing different ideas across two modalities is thus not essential for mismatch to predict learning. Rather, it appears to be the juxtaposition of different ideas across two distinct representational formats—an analog format underlying gesture versus a discrete segmented format underlying words or signs—that is responsible for mismatch predicting learning.

GESTURE'S ROLE IN THE CLINIC AND THE CLASSROOM

The gestures learners spontaneously produce when they talk provide insight into their thoughts—often their cutting-edge thoughts. This fact opens up the possibility that gesture can be used to assess children's knowledge in the clinic and the classroom. Moreover, the fact that encouraging learners to gesture on a task can lead to better understanding of the task opens up the possibility that gesture can also

Aphasia:

an impairment in language ability caused by trauma, stroke, tumor, infection, or dementia

be used to change what children know in the clinic or the classroom.

Clinical Situations

Gesture can provide unique information about the nature and extent of underlying deficits in children and adults with a variety of language and communication disorders (Capone & McGregor 2004, Goldin-Meadow & Iverson 2010). Studies of a range of disordered populations across the lifespan have identified subgroups on the basis of gesture use and then examined future language in relation to subgroup membership. For example, spontaneous gesture production at 18 months in children with early focal brain injury can be used to distinguish children who are likely to recover from initial language delay from children who are not likely to recover (Sauer et al. 2010).

As another example, infants subsequently diagnosed with autism produce fewer gestures overall and almost no instances of pointing at 12 months, compared to typically developing infants at the same age (Osterling & Dawson 1994; see also Bernabei et al. 1998). This finding has been replicated in prospective studies of younger infant siblings of older children already diagnosed with autism. Infant siblings who later turn out to be diagnosed with autism have significantly smaller gesture repertoires at 12 and 18 months than infant siblings who do not receive such a diagnosis, and than a comparison group of infants with no family history of autism. Importantly, at early ages, gesture seems to be more informative about future diagnostic status than word comprehension or production—differences between infant siblings later diagnosed with autism and the two comparison groups do not emerge in speech until 18 months of age (Mitchell et al. 2006). Future work is needed to determine whether gesture use (or its lack) is a specific marker of autism or a general marker of language and communication delay independent of etiology.

Early gesture thus appears to be a sign of resilience in children with language difficulties and an indicator that they may not be delayed

in the future. In contrast, adults with aphasia who gesture within the first months after the onset of their illness appear to do less well in terms of recovery than aphasic adults who do not gesture (Braddock 2007). An initial pattern of compensation via gesture thus appears to be a positive prognostic indicator for language recovery in children but not in adults. These findings suggest that encouraging gesture might be more helpful to children with language disabilities than to adults.

Educational Situations

Because children's gestures often display information about their thinking that they do not express in speech, gesture can provide teachers with important information about their pupils' knowledge. As reviewed previously, there is evidence that teachers not only detect information that children express in gesture (e.g., Alibali et al. 1997) but also alter their input to children as a function of those gestures (Goldin-Meadow & Singer 2003).

It is also becoming increasingly clear that the gestures teachers produce during their lessons matter for students' learning. Many studies have shown that lessons with gestures promote deeper learning (i.e., new forms of reasoning, generalization to new problem types, retention of knowledge) better than lessons without gestures. For example, Church et al. (2004) examined first-grade students learning about Piagetian conservation from videotaped lessons and found that, for native English speakers, 91% showed deep learning (i.e., added new same judgments) from a speech-plus-gesture lesson, compared to 53% from a speech-only lesson. For Spanish speakers with little English proficiency, 50% showed deep learning from the speech-plus-gesture lesson, compared to 20% from the speech-only lesson. As a second example, Valenzeno et al. (2003) studied preschoolers learning about symmetry from a videotaped lesson and found that children who viewed a speech-plus-gesture lesson succeeded on more than twice as many posttest problems as children who viewed a speech-only lesson

(2.08 versus 0.85 out of 6). Clearly, teachers' gestures can have a substantial impact on student learning. A teacher's inclination to support difficult material with gesture may be precisely what their students need to grasp challenging material.

Building on growing evidence that teachers' gestures matter for student learning, recent studies have sought to characterize how teachers use gesture in naturalistic instructional settings (e.g., Alibali & Nathan 2012, Richland et al. 2007). Other research has sought to instruct teachers about how to effectively use gesture (Hostetter et al. 2006). Given that teachers' gestures affect the information that students take up from a lesson, and given that teachers can alter their gestures if they wish to do so, it may be worthwhile for teachers to use gesture intentionally, in a planned and purposeful fashion, to reinforce the messages they intend to convey.

In light of evidence that the act of gesturing can itself promote learning, teachers and clinicians may also wish to encourage children and patients to produce gestures themselves. Encouraging children to gesture may serve to activate their implicit knowledge, making them particularly receptive to instruction (Broaders et al. 2007). Teachers may also encourage their students to gesture by producing gestures of their own. Cook & Goldin-Meadow (2006) found that children imitated their instructor's gestures in a lesson about a mathematics task and, in turn, children's gestures predicted their success on the math problems after

instruction. Thus, teacher gesture promoted student gesture, which in turn fostered cognitive change.

CONCLUSIONS

We have seen that gesture is a robust part of human communication and can be harnessed in a variety of ways. First, gesture reflects what speakers know and can therefore serve as a window onto their thoughts. Importantly, this window often reveals thoughts that speakers do not even know they have. Encouraging speakers (e.g., students, patients, witnesses) to gesture thus has the potential to uncover thoughts that would be useful for individuals who interact with these speakers (teachers, clinicians, interviewers) to know. Second, gesture can change what speakers know. The act of producing gesture can bring out previously unexpressed thoughts and may even introduce new thoughts into a speaker's repertoire, altering the course of a conversation or developmental trajectory as a result. Encouraging gesture thus also has the potential to change cognition. Finally, gesture provides building blocks that can be used to construct a language. By watching how children and adults who do not already have a language put those blocks together, we can observe the process of language creation first hand. Our hands are with us at all times, and we routinely use them for communication. They thus provide both researchers and learners with an ever-present tool for understanding how we talk and think.

SUMMARY POINTS

1. The gestures that speakers produce along with their speech not only help speakers produce, and listeners understand, that speech, but they can also convey information on their own (i.e., listeners can glean information from gesture that is not conveyed in the accompanying speech).
2. The gestures children produce at the earliest stages of language learning precede speech and predict which nouns a child is likely to acquire and when the child will begin to produce two-word utterances.

3. The gestures children produce can play a causal role in language learning by eliciting timely input from parents and other adults and by providing an early medium in which to practice expressing ideas symbolically.
4. After language has been mastered, gesture continues to predict learning in both children and adults. Learners who convey information in gesture that differs from the information in speech on a particular task are likely to learn when given instruction in that task.
5. The gestures that children and adults produce can play a causal role in learning through social mechanisms, that is, by conveying information about learners' knowledge states to listeners who, in turn, alter the input they provide to the learners.
6. The gestures that children and adults produce can also alter the state of their own knowledge, thus playing a more direct role in learning through cognitive mechanisms (e.g., by activating implicit knowledge, by lightening their cognitive load, by highlighting perceptual or motor information).
7. When the manual modality is called upon to fulfill the communicative functions of language, as in sign languages of the deaf, it also assumes language's segmented and combinatorial form.
8. The segmentation and combination that characterize established languages, signed or spoken, is also found in newly emerging sign languages, for example, in deaf children whose hearing losses prevent them from learning the speech that surrounds them and whose hearing parents have not exposed them to sign, and in hearing speakers asked to communicate using their hands and not their mouths.

FUTURE ISSUES

1. We know very little about individual differences with respect to gesturing. Are some individuals particularly likely to produce gestures not just on one task but on all tasks? Are some particularly likely to rely on gestures when listening to speech? Are some particularly likely to rely on gesture in a learning task, and, if so, are these the same individuals (that is, does reliance on gesture in one area predict reliance on gesture in another)?
2. When gesture is produced at the earliest stage of language learning, it often substitutes for a word that the child has not yet acquired. Gesture continues throughout development to convey ideas that are not expressed in speech, but often those ideas cannot easily be translated into a single word. As a result, once children have become proficient language users, we might expect to see a change in the kinds of ideas that gesture conveys. Future work is needed to determine when this transition takes place.
3. Encouraging school-aged children to gesture on a task makes those children ready to profit from instruction on that task, suggesting that gesture can play a causal role in learning. A question for future work is whether gesture plays the same instrumental role in all learners (e.g., young learners who are at the earliest stages of language learning; old learners who may be losing their capacities) and on all tasks (e.g., spatial tasks whose properties are particularly easy to capture in gesture; nonspatial tasks, such as moral reasoning, whose properties are less easily conveyed through gesture).

4. The absence of gesturing has been found to be a characteristic of young children who are later diagnosed as autistic. A question for future research is whether gesture use (or its absence) is a specific marker of autism or a general marker of language and communication delay independent of etiology.
5. Early gesture has been found to be a sign of resilience in children with language difficulties and an indicator that children who gesture may not be delayed in the future. In contrast, adults with aphasia who gesture within the first months after the onset of their illness often do less well in terms of recovery than aphasic adults who do not gesture. Future work is needed to determine how robust this contrast is.
6. Growing evidence indicates that teachers' gestures matter for students' learning. However, future work is needed to establish a set of empirically based recommendations for teachers about how to most effectively use gesture in classrooms and other instructional settings.
7. Homesigns, the gesture systems profoundly deaf children born to hearing parents use to communicate if they are not exposed to sign language, exhibit many—but not all—of the properties found in natural language. Exploring the conditions under which homesign takes on more and more linguistic properties would provide insight into factors that may have shaped human language in the past and that may influence current-day language learning.

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