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Constructing communication by hand

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Abstract

I focus here on how children construct communication, looking in particular at places where the language model of the community exerts less influence on the child. I first describe the gesture systems constructed by deaf children who are unable to acquire speech and have not been exposed to a sign language. These children are constructing their communication systems in large part without benefit of conventional linguistic input. As a result, the children's gestures reflect skills that they themselves bring to the language-learning situation, skills that interact with linguistic input when that input is available. I then describe the gestures that hearing children produce when they talk. Gesture does not need to assume a language-like role for these children and indeed it does not. Nevertheless, the gestures these speaking children produce convey information and that information is often different from the information found in their talk. Gesture thus allows the children to reach beyond the confines of the language they are speaking. Both cases highlight the child's contribution to the communication process and provide unique opportunities to observe the child's skills as language-maker.

Keywords: Communication; Deafness; Gestures; Homesigns; Language

1. How to discover the child's contribution to communication

Children learn the language to which they are exposed. In fact, they seem to be quite sensitive to the particular patterns found in their language and, in many respects, already behave like native speakers from the earliest moments of language-learning (Berman & Slobin, 1994; Choi & Bowerman, 1991). Thus,

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language-learning is directly influenced by the language model the community provides for children. However, it is equally clear that children are not merely passive recipients of this language model. At the early stages of language-learning, children produce short and simple sentences, many of which are not likely to have been heard before. For example, a child sentence such as "mommy sock" is not likely to be part of any adult's linguistic repertoire. Nevertheless, "mommy sock" does follow a pattern, one that has been constructed out of the principles underlying the adult sentences that the child does hear (Bloom, 1970).

This paper describes an approach to the construction process that underlies communication. The difficulty in exploring this process lies in identifying the child's contribution to it. As noted above, even the earliest steps the child takes in language-learning are heavily influenced by the language model to which the child is exposed. How then can we tell what role the child assumes?

One approach to this question is to observe children who have *not* been exposed to a conventional language model. Whatever progress such children make toward constructing a language-like system must, in large part, be guided by the children themselves. I begin this paper by examining communication in children who have not experienced a usable language model — deaf children whose profound hearing losses prevent them from acquiring a spoken language and whose hearing parents have not exposed them to a sign language. These children are lacking an accessible language model. Nevertheless, they invent gesture systems that they use to communicate with the hearing individuals in their worlds (Goldin-Meadow, 2002a). These gesture systems display quite clearly the skills that children bring to communication.

A second approach to discovering the child's role in communication is to examine the gestures that hearing children produce when they talk. These spontaneous gestures often convey information that is not conveyed in the talk they accompany (Goldin-Meadow, 2002b). The gestures therefore allow children (and all speakers) to reach beyond the confines of the language they are speaking and, as a result, offer a unique picture of the child's contribution to communication. In the second part of this paper, I examine communication in children who have learned their language from a language model, but with an eye to the additional information that the children convey through their hands.

2. Constructing communication out of gesture in the absence of a language model

2.1. Background on deafness and language-learning

Deaf children born to deaf parents and exposed from birth to a conventional sign language such as American Sign Language (ASL) acquire that language naturally; that is, these children progress through stages in acquiring sign language similar to those of hearing children acquiring a spoken language (Newport & Meier, 1985).

However, 90% of deaf children are not born to deaf parents who could provide early exposure to a conventional sign language. Rather, they are born to hearing parents who, quite naturally, expose their children to speech (Hoffmeister & Wilbur, 1980). Unfortunately, it is extremely uncommon for deaf children with severe to profound hearing losses to acquire the spoken language of their hearing parents naturally, that is, without intensive and specialized instruction. Even with instruction, deaf children's acquisition of speech is markedly delayed when compared either to the acquisition of speech by hearing children of hearing parents, or to the acquisition of sign by deaf children of deaf parents. By age 5 or 6, and despite intensive early training programs, the average profoundly deaf child has limited linguistic skills in speech (Conrad, 1979; Mayberry, 1992; Meadow, 1968). Moreover, although many hearing parents of deaf children send their children to schools in which one of the manually coded systems of English is taught, some hearing parents send their deaf children to "oral" schools in which sign systems are neither taught nor encouraged; thus, these deaf children are not likely to receive input in a conventional sign system.

My colleagues and I have studied 10 American deaf children each with severe (70–90 dB) to profound (>90 dB) bilateral hearing losses. Each child was born to hearing parents who had chosen to educate their child using an oral method. At the time of our observations, the children ranged in age from 14 months to 4 years, 10 months and had made little progress in oral language, occasionally producing single words but never combining those words into sentences. In addition, at the time of our observations, the children had not been exposed to ASL or to a manual code of English. As preschoolers in oral schools for the deaf, the children spent very little time with the older deaf children in the school who might have had some knowledge of a conventional sign system (i.e., the preschoolers only attended school a few hours a day and were not on the playground at the same time as the older children). In addition, the children's families knew no deaf adults socially and interacted only with other hearing families, typically those with hearing children. One of the primary reasons we were convinced that the children in our studies had had no exposure to a conventional sign system at the time of our observations was that they did not know even the most common lexical items of ASL or Signed English (when a native deaf signer reviewed our tapes, she found no evidence of any conventional signs; moreover, when we informally presented to the children common signs such as those for mother, father, boy, girl, dog, we found that they neither recognized nor understood any of these signs).

Under such inopportune circumstances, these deaf children might be expected to fail to communicate at all, or perhaps to communicate only in non-symbolic ways. The impetus for communication might have to come from a language model, which all of these children lacked. However, this turns out not to be the case. Many studies have shown that deaf children will spontaneously use gestures — called "homesigns" — to communicate if they are not exposed to a conventional sign language (Fant, 1972; Lenneberg, 1964; Moores, 1974; Tervoort, 1961). As an example, consider one homesigner who had just blown a bubble and described the act in gesture. He first held his index finger at his mouth and puffed, and then fashioned his hand into an O-shape and moved it forward — roughly translated as "I blow the bubble and it goes forward" (Goldin-Meadow, 2002a). Children who use gesture in this way are clearly communicating. What is of interest here is the particular constructions that the children introduce into their gesture systems for these are the properties of language that a child can fashion even without benefit of linguistic input — what I have previously called the "resilient" properties of language (Goldin-Meadow, 1982, 2002a).

2.2. The resilient properties of language

The linguistic properties that appear in the deaf children's gesture systems are resilient — likely to crop up in a child's communications whether or not that child is exposed to a conventional language model. Table 1 lists the properties

Table 1
The resilient properties of language

The resilient property	As instantiated in the deaf children's gesture systems
Words	
Stability	Gesture forms are stable and do not change capriciously with changing situations
Paradigms	Gestures consist of smaller parts that can be recombined to produce new gestures with different meanings
Categories	The parts of gestures are composed of a limited set of forms, each associated with a particular meaning
Arbitrariness	Pairings between gesture forms and meanings can have arbitrary aspects, albeit within an iconic framework
Grammatical functions	Gestures are differentiated by the noun, verb, and adjective grammatical functions they serve
Sentences	
Underlying frames	Predicate frames underlie gesture sentences
Deletion	Consistent production and deletion of gestures within a sentence mark particular thematic roles
Word order	Consistent orderings of gestures within a sentence mark particular thematic roles
Inflections	Consistent inflections on gestures mark particular thematic roles
Recursion	Complex gesture sentences are created by recursion
Redundancy reduction	Redundancy is systematically reduced in the surface of complex gesture sentences
Language use	
Here-and-now talk	Gesturing is used to make requests, comments, and queries about the present
Displaced talk	Gesturing is used to communicate about the past, future, and hypothetical
Narrative	Gesturing is used to tell stories about self and others
Self-talk	Gesturing is used to communicate with oneself
Metalanguage	Gesturing is used to refer to one's own and others' gestures

of language that we have found thus far in the 10 deaf children's gesture systems (Goldin-Meadow, 2002a). There may, of course, be many others — just because we haven't found a particular property in a deaf child's homesign gesture system doesn't mean it's not there. The table lists properties at the word- and sentence-levels, as well as properties of language use, and details how each property is instantiated in the deaf children's gesture systems.

2.2.1. *Words*

The deaf children's gesture words have five properties that are found in all natural languages. The gestures are *stable* in form, although they needn't be. It would be easy for the children to make up a new gesture to fit every new situation (and, indeed, that appears to be what hearing speakers do when they gesture along with their speech, cf. McNeill, 1992). But that's not what the deaf children do. They develop a stable store of forms which they use in a range of situations — they develop a lexicon, an essential component of all languages (Goldin-Meadow, Butcher, Mylander, & Dodge, 1994).

Moreover, the gestures the children develop are composed of parts that form *paradigms*, or systems of contrasts. When the children invent a gesture form, they do so with two goals in mind — the form must not only capture the meaning they intend (a gesture–world relation), but it must also contrast in a systematic way with other forms in their repertoire (a gesture–gesture relation). In addition, the parts that form these paradigms are *categorical*. For example, one child used a *Fist* handshape to represent grasping a balloon string, a drumstick, and handlebars — grasping actions requiring considerable variety in diameter in the real world. The child did not distinguish objects of varying diameters within the *Fist* category, but did use his handshapes to distinguish objects with small diameters as a set from objects with large diameters (e.g., a cup, a guitar neck, the length of a straw) which were represented by a *CLarge* hand. The manual modality can easily support a system of analog representation, with hands and motions reflecting precisely the positions and trajectories used to act on objects in the real world. But the children don't choose this route. They develop categories of meanings that, although essentially iconic, have hints of *arbitrariness* about them (the children don't, for example, all have the same form-meaning pairings for handshapes, Goldin-Meadow, Mylander, & Butcher, 1995).

Finally, the gestures the children develop are differentiated by *grammatical function*. Some serve as nouns, some as verbs, some as adjectives. As in natural languages, when the same gesture is used for more than one grammatical function, that gesture is marked (morphologically and syntactically) according to the function it plays in the particular sentence (Goldin-Meadow et al., 1994). For example, if a child were to use a twisting gesture in a verb role, that gesture would likely be produced near the jar to be twisted open (i.e., it would be inflected), it would not be abbreviated, and it would be produced *after* a pointing gesture at the jar. In contrast, if the child were to use the twisting gesture in a noun role, the gesture would likely be produced in neutral position near the chest (i.e., it would not be inflected), it would be abbreviated (produced with one twist rather than several), and it would occur *before* the pointing gesture at the jar.

2.2.2. Sentences

The deaf children's gesture sentences have six properties found in all natural languages. Underlying each sentence is a *predicate frame* that determines how many arguments can appear along with the verb in the surface structure of that sentence (Goldin-Meadow, 1985). For example, four slots underlie a gesture sentence about transferring an object, one for the verb and three for the arguments (actor, patient, recipient). In contrast, three slots underlie a gesture sentence about eating an object, one for the verb and two for the arguments (actor, patient).

Moreover, the arguments of each sentence are marked according to the thematic role they play. There are three types of markings that are resilient (Goldin-Meadow & Mylander, 1984; Goldin-Meadow et al., 1994):

1. *Deletion* — The children consistently produce and delete gestures for arguments as a function of thematic role; for example, they are more likely to delete a gesture for the object or person playing the role of transitive actor (soldier in "soldier beats drum") than they are to delete a gesture for an object or person playing the role of intransitive actor (soldier in "soldier marches to wall") or patient (drum in "soldier beats drum").
2. *Word order* — The children consistently order gestures for arguments as a function of thematic role; for example, they place gestures for intransitive actors and patients in the first position of their two-gesture sentences (soldier-march; drum-beat).
3. *Inflection*[1] — The children mark with inflections gestures for arguments as a function of thematic role; for example, they displace a verb gesture in a sentence toward the object that is playing the patient role in that sentence (the "beat" gesture would be articulated near, but not on, a drum).

In addition, *recursion*, which gives natural languages their generative capacity, is a resilient property of language. The children form complex gesture sentences out of simple ones (Goldin-Meadow, 1982). For example, one child pointed at me, produced a "wave" gesture, pointed again at me, and then produced a "close" gesture to comment on the fact that I had waved before closing the door — a complex sentence containing two propositions: "Susan waves" (proposition 1) and "Susan closes door" (proposition 2). The children systematically combine the predicate frames underlying each simple sentence, following principles of

[1] I follow sign language researchers in using the term "inflection" for the displacement of gestures away from neutral space (the chest-level area). The directionality of an inflecting verb reflects agreement of the verb with its subject or object, just as a verb in English agrees with its subject in number. Verbs in ASL agree with the person (I, you, he/she/it) of its subject or object. The first person affix places the sign near the signer's body; the second person affix places the sign in the direction of the addressee; and the third person affix places the sign at the locus assigned to that entity (Padden, 1983).

sentential and phrasal conjunction. When there are semantic elements that appear in both propositions of a complex sentence, the children have a systematic way of *reducing redundancy*, as do all natural languages (Goldin-Meadow, 1982, 1987).

2.2.3. Language use

The deaf children use their gestures for five central functions that all natural languages serve. They use gestures to make requests, comments, and queries about things and events that are happening in the situation — that is, to communicate about the *here-and-now*. Importantly, however, they also use their gestures to communicate about the non-present — *displaced* objects and events that take place in the past, the future, or in a hypothetical world (Butcher, Mylander, & Goldin-Meadow, 1991; Morford & Goldin-Meadow, 1997).

In addition to these rather obvious functions that language serves, the children use their gestures to communicate with themselves — to *self-talk* (Goldin-Meadow, 2002a). The children also use their gestures to refer to their own or to others' gestures — for *metalinguistic* purposes (Singleton, Morford, & Goldin-Meadow, 1993). And finally, the children use their gestures to tell stories about themselves and others — to *narrate* (Phillips, Goldin-Meadow, & Miller, 2001). They tell stories about events they or others have experienced in the past, events they hope will occur in the future, and events that are flights of imagination. For example, in response to a picture of a car, one child produced a "break" gesture, an "away" gesture, a pointing gesture at his father, a "car-goes-onto-truck" gesture. He paused and produced a "crash" gesture and repeated the "away" gesture. The child was telling us that his father's car had crashed, broken, and gone onto a tow truck. Note that, in addition to producing gestures to describe the event itself, the child produced what we have called a narrative marker — the "away" gesture, which marks a piece of gestural discourse as a narrative in the same way that "once upon a time" is often used to signal a story in spoken discourse (Phillips et al., 2001).

2.3. Using the spontaneous gestures of speakers as input

The deaf children we study are not exposed to a conventional sign language and thus cannot be fashioning their gestures after such a system. They are, however, exposed to the gestures that their hearing parents use when they speak. These gestures are likely to serve as relevant input to the gesture systems that the deaf children construct. The question is, what does this input look like and how do the children use it?

We first ask whether the gestures that the hearing parents use with their deaf children exhibit the same structure as their children's gestures. If so, these gestures could serve as a model for the deaf children's system. If not, we have an opportunity to observe how the children transform the input they do receive into a system of communication which has many of the properties of language.

2.3.1. The hearing parents' gestures are not structured like their deaf children's

Hearing parents gestures when they talk to young children (Bekken, 1989; Iverson, Capirci, Longobardi, & Caselli, 1999; Shatz, 1982) and the hearing parents of our deaf children are no exception. The deaf children's parents were committed to teaching them to talk and therefore talked to their children as often as they could. And when they talked, they gestured.

We looked at the gestures that the hearing mothers produced when talking to their deaf children. However, we looked at them not like they were meant to be looked at, but as a deaf child might look at them. We turned off the sound and analyzed the gestures using the same analytic tools that we used to describe the deaf children's gestures (Goldin-Meadow & Mylander, 1983, 1984). We found that the hearing mothers' gestures do not have structure when looked at from a deaf child's point of view.

Going down the list of resilient properties displayed in Table 1, we find no evidence of structure at any point in the mothers' gestures. With respect to gestural "words," the mothers did not have a *stable* lexicon of gestures (Goldin-Meadow et al., 1994); nor were their gestures composed of *categorical* parts that either formed *paradigms* (Goldin-Meadow et al., 1995) or varied with *grammatical function* (Goldin-Meadow et al., 1994). With respect to gestural "sentences," the mothers rarely concatenated their gestures into strings and thus provided little data from which we (or their deaf children, for that matter) could abstract *predicate frames* or *deletion*, *word order*, and *inflectional* marking patterns (Goldin-Meadow & Mylander, 1984). Whereas all of the children produce complex sentences displaying *recursion*, only some of the mothers did and they first produced these productions after their children (Goldin-Meadow, 1982). With respect to gestural use, the mothers did not make *displaced reference* with their gestures (Butcher et al., 1991), nor did we find evidence of any of the other uses to which the children put their gestures, including *story-telling* (e.g., Phillips et al., 2001).

Of course, it may be necessary for the deaf children to see hearing people gesturing in communicative situations in order to get the idea that gesture can be appropriated for the purposes of communication. However, in terms of how the children *structure* their gestured communications, there is no evidence that this structure comes from the children's hearing mothers. Thus, although the deaf children may be using hearing peoples' gestures as a starting point, they go well beyond that point — transforming the gestures they see into a system that looks very much like language.

2.3.2. How to study the deaf child's transformation of gesture into homesign: a cross-cultural approach

How can we learn more about this process of transformation? The fact that hearing speakers across the globe gesture differently when they speak affords us with an excellent opportunity to explore if — and how — deaf children make use of the gestural input that their hearing parents provide. For example, the gestures that accompany Spanish and Turkish look very different from those that accompany

English and Mandarin. As described by Talmy (1985), Spanish and Turkish are verb-framed languages, whereas English and Mandarin are satellite-framed languages. This distinction depends primarily on the way in which the path of a motion is packaged. In a satellite-framed language, path is encoded outside of the verb (e.g., *down* in the sentence "he flew down") and manner is encoded in the verb itself (*flew*). In contrast, in a verb-framed language, path is bundled into the verb (e.g., *sale* in the Spanish sentence "sale volando" = exits flying) and manner is outside of the verb (*volando*). One effect of this typological difference is that manner is often omitted from Spanish sentences (Slobin, 1996).

However, McNeill (1998) has observed an interesting compensation — although manner is omitted from Spanish-speakers' *talk*, it frequently crops up in their *gestures*. Moreover, and likely because Spanish-speakers' manner gestures do not co-occur with a particular manner word, their gestures tend to spread through multiple clauses (McNeill, 1998). As a result, Spanish-speakers' manner gestures are longer and may be more salient to a deaf child than the manner gestures of English- or Mandarin-speakers. Turkish-speakers also produce gestures for manner relatively frequently. In fact, Turkish-speakers commonly produce gestures that convey *only* manner (e.g., fingers wiggling in place = manner alone vs. fingers wiggling as the hand moves forward = manner + path; Kita, 2000; Ozyurek & Kita, 1999). Manner-only gestures are rare in English- and Mandarin-speakers.

In general, the gesture models that Spanish- and Turkish-speakers present to their deaf children seem to be richer (with gestures for more different types of semantic elements), but also more variable, than the gesture models presented by English- and Mandarin-speakers. This variability might provide deaf children with a stepping-stone to a more complex linguistic system. Alternatively, variability could make it *more difficult* to abstract the essential elements of a semantic relation and thus result in a less language-like system. By comparing the different gesture models that speakers of Spanish and Turkish versus English and Mandarin present to the deaf child, we have an ideal paradigm within which to observe the relation between adult input and child output — and a unique opportunity to observe the child's skills as language-maker.[2]

These four cultures — Spanish, Turkish, American, and Chinese — thus offer an excellent opportunity to examine the effects of hearing speakers' gestures on the gesture systems developed by deaf children. Our plan in future work is to take advantage of this opportunity. If deaf children in all four cultures develop gesture systems with the same structure despite wide differences in the gestures they see, we will have strong evidence of the biases children themselves must bring to a communication situation. If, however, the children differ in the gesture

[2] We have already found that American deaf children exposed only to the gestures of their hearing English-speaking parents create gesture systems that are very similar in structure to the gesture systems constructed by Chinese deaf children exposed to the gestures of their hearing Mandarin-speaking parents (Goldin-Meadow & Mylander, 1998). In future work, we will compare these children's gesture systems to those of Spanish and Turkish deaf children of hearing parents.

systems they construct, we will be able to explore how a child's construction of a language-like gesture system can be influenced by the gestures he or she sees.

3. Constructing communication out of gesture along with a language model

3.1. Gesture reflects thoughts not found in speech

We have seen that when children are not exposed to a conventional language model, they are able to exploit gesture to fashion their own communication systems. But what happens to gesture when children *are* exposed to a conventional language model? Hearing children do gesture and, indeed, they produce gestures even before they begin to produce words. However, their gestures do not need to take on language-like properties — speech assumes that role for these children. What role, then, does gesture play in a hearing child's communication? It turns out that the gestures a hearing child produces extend the range of meanings that the child is able to convey. Moreover, when taken in relation to the speech it accompanies, a child's gesture on a task can provide insight into whether the child is ready to learn that task. I illustrate this phenomenon in three domains, each mastered at a different age.

3.1.1. Gesture in the early stages of language-learning

At the early stages of language development, children are able to produce words one at a time, but are not yet able to combine those words into even very short two-word sentences. However, at this same time, they are able to use gesture as a supplement to their words in order to express the equivalent of a one-proposition idea (Goldin-Meadow & Morford, 1985; Greenfield & Smith, 1976; Masur, 1982, 1983; Morford & Goldin-Meadow, 1992; Zinober & Martlew, 1985). For example, one child pointed at a drawer and said "open" (thus conveying the proposition "open drawer"); another pointed at a turtle and said "go" (conveying the proposition "turtle goes"); yet another produced a clawing gesture and said "bear" (conveying the proposition "bear claws"); finally, one child produced a gesture for big and said "monster" (conveying the proposition "monster is big") (Goldin-Meadow & Butcher, in press). Note that the child is expressing two semantic elements, one in gesture and one in speech. If gesture and speech are considered to be a single system, these combinations are, in effect, short one-proposition sentences.

Combinations in which gesture and speech convey different — and, in this sense, "mismatching" — information could be a stepping-stone on the way to two-word combinations expressing these same propositions. In a study of six children making the transition from one-word to two-word speech (Goldin-Meadow & Butcher, in press), we found that all of children produced gesture–speech combinations of this type *before* they produced their first two-word utterance (e.g., a child would produce "dada"+point at dad's hat prior to "dada hat"). More impressive, however, is the fact that the age at which the children first produced these mismatching gesture–speech combinations correlated with the age at which they first produced two-word utterances ($r_s = .90$, $P < .05$). Thus, the children who were first to produce mismatching gesture–speech combinations were also first to produce two-word utterances.

Importantly, the correlation between gesture–speech combinations and two-word speech was specific to utterances in which gesture and speech conveyed *different* information — we didn't find the pattern for utterances in which gesture and speech conveyed the *same* information (i.e., matches, e.g., "hat"+point at dad's hat). The correlation between the onset of matches and the onset of two-word utterances was low and unreliable ($r_s = .46$, ns). Thus, it appears to be the ability to use gesture and speech to convey different components of a proposition — and not just the ability to use gesture and speech in a single utterance — that predicts the onset of two-word utterances (see also Capirci, Montanari, & Volterra, 1998; Goodwyn & Acredolo, 1998).

We have found that gesture can convey information that is not found in a child's speech. Moreover, by looking at the information conveyed in gesture in relation to the information conveyed in the speech it accompanies, we can get a good sense of when a child is about to move onto two-word speech.

3.1.2. Gesture in the acquisition of conservation of quantities

When children are asked to justify responses to a series of Piagetian tasks, they gesture (Church & Goldin-Meadow, 1986). Moreover, they use those gestures to convey substantive information about the task. Take, for example, a liquid conservation task. The child is shown two identical glasses containing the same amount of liquid. The liquid from one glass is poured into a short wide dish, and the child is asked whether the glass and the dish contain the same amount of water. Non-conservers say "no" and might justify this judgment by explaining that "it's a different amount because you poured it." At the same time, many children augment this verbal response by producing a pouring motion in gesture.

Interestingly, however, some children do not use their hands to express the same information that they express in speech. They use them to convey additional information. For example, a child again says, "it's a different amount because you poured it," but this child gestures the shape of the container rather than the pouring action (i.e., two C-shaped hands positioned with fingertips touching to form a round circle). The child has focused on the experimenter's pouring motions in speech, but on the shape of the container in gesture — the child has produced a gesture–speech mismatch.

Do children who produce many of these gesture–speech mismatches differ from children who produce few in their potential for learning? We conducted a training study to find out (Church & Goldin-Meadow, 1986). We first gave 5–8-year-old children a pretest of six quantity problems and assessed their understanding of conservation. We also used the pretest to determine whether the children produced primarily gesture–speech matches (and called those children "matchers") or produced primarily gesture–speech mismatches (the "mismatchers"). We then gave all of the children instruction in the task. After the instruction session, the children were again given the six conservation problems and we assessed their improvement, if any, from pretest to posttest. We found that the children who were mismatchers on the pretest made significantly more progress than children who were matchers. Thus, gesture–speech mismatch in a child's explanations of conservation is an excellent sign that the child is ready to learn conservation. Gesture not only reveals a child's unspoken thoughts about quantities, but it also can give us notice that the child may be ready to make progress on the task.

3.1.3. Gesture in the acquisition of mathematical equivalence

Mathematical equivalence is the notion that the two sides of an equation must be equivalent. Fourth grade children in the United States can easily solve simple problems such as $4 + 5 + 3 = \_\_$ and thus, on the surface, *appear* to understand that the two sides of an equation must add to the same amount. However, when asked to solve the problem $4+5+3 = \_\_+3$, they frequently err, either putting 12 in the blank (adding all the numbers on the left side of the equation) or 15 (adding all of the numbers in the problem). We videotaped children explaining how they solved the more complex addition problems, and found that most children produced gestures along with their explanations (Perry, Church, & Goldin-Meadow, 1988). Many children gave incorrect explanations in both speech and gesture — "I added 4 plus 5 plus 3 plus 3 equals 15," while pointing at the 4, the 5, the 3 on the left side of the equation, the 3 on the right side of the equation, and the blank.

However, some children produced gesture–speech mismatches. For example, one child said, "I added 4 plus 5 plus 3 plus 3 equals 15," while pointing with a V-shaped hand at the 4 and the 5 and then pointing at the blank. The child produced an add-all-numbers strategy in speech, but in gesture focused on the two numbers that can be grouped and summed to get the correct answer (a grouping strategy). The child produced an incorrect strategy in speech, but a correct one in gesture. Children also produced mismatches containing two incorrect strategies — "I added 4 plus 5 plus 3 equals 12," while pointing at the 4, the 5, the 3 on the left side of the equation, the 3 on the right side of the equation, and the blank. The child produced an incorrect add-to-equal-sign strategy in speech, and an incorrect add-all-numbers strategy in gesture.

We conducted a training study comparable to our conservation study (Perry et al., 1988). We gave children in the fourth and fifth grades a pretest of six addition problems to assess their understanding of mathematical equivalence, and to divide the children into matchers and mismatchers. We then gave the children instruction in the principle underlying the addition problems — the children were told that the goal of the problem was to make both sides of the equation equal. After the instruction session, the children were again given six addition problems and a series of novel addition and multiplication problems that tested their ability to generalize what they had learned.

As in our conservation study, many more mismatchers were successful on the posttest than matchers (Perry et al., 1988). Moreover, the mismatchers, but not the matchers, were successful on the generalization test. The mismatchers had not only learned how to solve the equivalence problems, but also to extend that knowledge to different problem types. Again, mismatch predicted who would learn and who would not.

We have seen that the gestures a child produces while talking offer a unique perspective on that child's thoughts. Children can use gesture to go beyond their words (see also Garber, Alibali, & Goldin-Meadow, 1998). But gesture may do more than reflect a child's thoughts — it may also play a role in changing those thoughts. In the next two sections, I review evidence suggesting that gesture can bring about cognitive change, either by shaping the child's learning environment and thereby having an indirect effect on the learner, or by affecting the learner directly.

3.2. Gesture can change thought by its effects on social interaction

Gesture may be the first place a child displays a new thought. If the adults who interact with this child are able to read the child's gestures, they will have insight into the ideas that the child is currently working on and could, as a result, change the way they interact with the child. We know that adults — even those who have not been trained to code gesture — are able to glean substantive information from the gestures children produce if those gestures are selected for clarity and shown twice on videotape (Alibali, Flevares, & Goldin-Meadow; 1997; Goldin-Meadow, Wein, & Chang, 1992; see also Beattie & Shovelton, 1999; Kelly & Church, 1997, 1998; McNeill, Cassell, & McCullough, 1994; Thompson & Massaro, 1986). Indeed, adults can even read children's gestures when the gestures are unedited and observed "live" (Goldin-Meadow & Sandhofer, 1999). But reading gesture as an observer of an interaction is not the same as reading it as a participant in the interaction. Nor do these studies tell us whether adults profit from the information they glean from a child's gestures, and use it to shape their ongoing interactions with that child.

To explore this question, we asked eight adults, all of whom were experienced teachers, to instruct third and fourth grade children in mathematical equivalence (Goldin-Meadow & Singer, 2002). Each adult instructed from four to six children individually. The adults did not know the children they were asked to instruct so whatever reactions they did have to the children had to be based on the cues the children produced during the tutorials. The adult watched as a child was given a set of six pretest mathematical equivalence problems to solve at the board and thus had some sense of each child's understanding of the problem before beginning the instruction. The adults were given five problems to use when instructing each child but otherwise could use whatever techniques they thought appropriate. After the instruction, each child was given a posttest by the experimenter.

3.2.1. Mismatchers succeed after instruction

The first question is whether the children did, in fact, produce gesture–speech mismatches, thus revealing their readiness to learn the task. The children fell into three groups on the basis of if and when they produced mismatches: those who produced at least one mismatch during the pretest and continued to produce mismatches during instruction; those who produced mismatches for the first time during instruction; and those who never produced mismatches at any point during the study.

As we have now come to expect, the children's posttest scores varied as a function of gesture–speech mismatch. Children who produced mismatches during the pretest and instruction scored higher on the posttest than children who produced mismatches only during instruction who, in turn, scored higher than children who produced no mismatches at all. But unlike our previous training studies where we administered the instruction and thus made sure that it was the same across all learners (Church & Goldin-Meadow, 1986; Perry et al., 1988), the adults in this study were free to adapt their instruction to each child. Thus, the children's posttest performance could reflect, not only the child's readiness to learn the task, but also the type of instruction the adult gave that child. We therefore need to examine how the adults instructed each child and whether that instruction differed as a function of the child's gestures.

3.2.2. Adults provide mismatchers with variable instruction

We found that the adults did indeed instruct children differently as a function of their mismatches. The adults were more likely to teach a variety of different problem-solving strategies to children who produced mismatches than to children who didn't. In addition, they were more likely to produce mismatches of their own when interacting with the children who produced mismatches than to children who did not produce mismatches. Thus, the adults gave children who produced mismatches instruction that was variable in two senses — a relatively wide variety of problem-solving strategies in the instruction overall, and a variety of strategies within a single utterance (one in speech and one in gesture).

Exposing children to a variety of different approaches to a single problem seems, on the face of it, to be an excellent instructional plan. Indeed, Siegler (1994, 1996) argues that having many different problem-solving strategies in one's repertoire is good for learning. It is less clear why presenting two different strategies on the same problem — one in speech and the other in gesture, that is, a mismatch — might also be good for learning. We do know that children pay attention to the mismatching gestures that teachers produce in math tutorials (Goldin-Meadow, Kim, & Singer, 1999). Perhaps the contrast between the strategy presented in gesture and the strategy presented in speech makes the two strategies — and the fact that multiple approaches are possible — particularly salient to the child. In our current work, we are exploring whether it is important not only to present a variety of problem-solving strategies to the child, but also to present those strategies in a gesture–speech mismatch in order to promote learning. Whatever the outcome of our future studies, however, it is clear that adults are sensitive to the gestures that children produce and change how they respond accordingly.

3.2.3. Gesture and the zone of proximal development

Although it is rarely acknowledged explicitly in the course of conversation, gesture is literally “out there.” Gestures are concrete manifestations of ideas for all the world to see. When a child’s gestures convey information that is different from the information found in speech, those gestures can inform an adult of thoughts that the child has but cannot (or at least does not) express in speech. Gesture may therefore be one of the best ways that we have of discovering thoughts that are on the edge of a child’s competence — the child’s zone of proximal development (Vygotsky, 1978). A child’s zone of proximal development contains abilities that the child has not yet mastered but is actively working on — abilities that are ripe for change.What I am suggesting is that a child’s gestures can tell us which skills the child is working on, and can thus offer insight into the child’s zone of proximal development. We have found that children give off reliable cues to their cognitive state in gesture. Moreover, adults can interpret and respond to those cues. It is, of course, possible that the sensitivity to child mismatches that we see in our data may be limited to adults who are teachers and have had experience assessing children’s skills and teaching to those skills. However, this possibility seems unlikely — when asked to view videotapes of children solving either math (Alibali et al., 1997) or conservation (Goldin-Meadow, Wein, & Chang, 1992) problems, teachers turn out to be no better (and no worse) than undergraduate students at using gesture to assess children’s understanding. Thus, all adults, regardless of their experience with children, may well show the effect described here and provide more variable instruction to children who produce mismatches than to children who do not. In this way, the zone of proximal development may prove to be more than just a descriptive tool, and may actually play a role in developmental change.

3.3. Gesture can change thought by its direct effect on the learner

I have been emphasizing here the *indirect* role that gesture plays in cognitive change: the child gestures; the adult takes note and behaves differently; the child’s understanding of the task improves as a result of this changed behavior. Gesture’s effect on learning is mediated by the communication partner, thus making gesture an important social tool in cognitive change. But gesture may also play a more *direct* role in cognitive change. I provide two examples in the next sections.

3.3.1. Gesture can aid thinking by reducing cognitive effort

McNeill (1992) has suggested that gesture and speech form a single, integrated system in which the two modalities work together to convey meaning (see also Goldin-Meadow, Alibali, & Church, 1993). If this view is correct, gesturing might be expected to *reduce* demands on a speaker’s cognitive resources, freeing cognitive capacity to perform other tasks. Alternatively, since gesturing while speaking is likely to require motor planning, execution, and coordination of two separate cognitive and motor systems (Andersen, 1995; Petersen, Fox, Posner, Mintun, & Raichle, 1988), gesturing might be expected to *increase* a speaker’s cognitive load.

In order to determine the impact of gesturing on a speaker's cognitive load, we explored how gesturing on one task (explaining a math problem) affected performance on a second task (remembering a list of words) carried out at the same time (Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001). We asked children to solve a mathematical equivalence problem, and then gave them a list of words to remember while explaining how they solved the problem. The key to the design is that the children were doing the remembering and the explaining at the same time. On half of the trials, we gave the children no instructions. On the other half, the children were told to keep their hands flat on the table. If gesturing increases cognitive load, gesturing while explaining the math problems should take away from the resources available for remembering (Baddeley, 1986). Memory should then be *worse* when children gesture than when they do not gesture. Alternatively, if gesturing reduces cognitive load, gesturing while explaining the math problems should free up resources available for remembering. Memory should then be *better* when children gesture than when they do not.

We found that children remembered more words when gesturing than when not gesturing. Of course, it's possible that keeping one's hands flat on the table itself adds to cognitive load — if so, *not gesturing* might be making remembering words harder rather than gesturing making remembering words easier. The children in the study allowed us to address this concern. Some of them did not gesture on all of the trials when their hands were unconstrained. We therefore had three types of problems for these children: problems on which they chose to gesture; problem on which they chose not to gesture; and problems on which they were forced not to gesture. If being forced not to gesture is what's responsible for the effect, the children ought to remember fewer words only on these trials. If, on the other hand, not gesturing *per se* accounts for the effect, the children ought to remember the same number of words when they did not gesture, either by choice or by instruction, and that number ought to be less than the number of words they remembered when they chose to gesture. This, in fact, was the pattern we found — not only in children explaining mathematical problems, but also in adults explaining factoring problems (Goldin-Meadow et al., 2001).

Gesturing thus appears to save speakers cognitive resources on an explanation task, permitting the speakers to allocate more resources to a memory task. The effort saved by gesturing can then be used on some other task, one that would have been performed less well had the speaker not gestured on the first task. Gesturing thus allows speakers to do more with what they've got and, in this way, can also lead to cognitive change.

3.3.2. Gesturing can make it easy to think certain thoughts

Another way gesturing could contribute to cognitive change is by influencing the particular ideas that a learner entertains. Gesture offers a route, and a unique one, through which new information can be brought into the system. Because the representational formats underlying gesture are mimetic and analog rather than discrete, gesture permits speakers to represent ideas that lend themselves to these formats (e.g., shapes, sizes, spatial relationships) — ideas that, for whatever reason, may not be encoded in speech (Alibali, Kita, & Young, 2000; Goldin-Meadow, 2002b). Gesture thus provides a format that makes it easy for the child to discover certain ideas, and thus allows these novel ideas to be brought into the system earlier than they might have been without gesture. Once brought in, the new ideas can then serve as a catalyst for change.

The suggestion here is that gesture doesn't just reflect the incipient ideas that a learner has but actually helps the learner formulate and therefore develop these new ideas. In other words, the course of cognitive change may be different by virtue of the fact that the learner gestured. Of course, since gesture is available for all the world to see, it may be the *listener* who first discovers that a child is on the brink of a new insight. And, as we have seen, the listener could act on this information and provide just the right input to help the child solidify and further develop that insight. Thus, it may not always be easy to separate the direct and indirect roles gesture can play in cognitive change. The important point, however, is that gesture can cause cognitive change and not just reflect it.

4. Children take what they need from their input

When children are exposed to conventional linguistic input, they use it. Hearing children learn the spoken language that they hear. Yet they are not limited by the language they speak — they are able to use gesture to express thoughts that they do not seem to have words for. The manual modality provides children (and adults, for that matter) with an ideal means for circumventing whatever constraints of expression their language imposes upon them — it provides an excellent means for constructing thought outside the bounds of conventional language.

But gesture is versatile. When children are *not* exposed to conventional linguistic input, they rely on gesture to fill the breach. Deaf children who cannot learn a spoken language and have not been exposed to a sign language invent gesture systems that have many of the most fundamental properties of human language. Of course, children can go only so far when provided, not with a conventional sign language, but with the spontaneous gestures of hearing individuals to use as a basis for fashioning a linguistic system. Having a model, even an imperfect one, as input leads to a more elaborate linguistic system as output. For example, if provided with a model of ASL that is impoverished, a deaf child can achieve near native linguistic performance (Singleton & Newport, in press), thus surpassing deaf children who have only gesture to use as input. Children apply their language-making skills to whatever input they are given. The output depends, not only on those skills, but also on the quality of the input.

We can see the construction process most clearly when we compare the gestures hearing children use along with their speech to the gestures deaf children of hearing parents use in place of speech. Both groups of children are exposed to the spontaneous gestures that their hearing parents use when talking to them. The difference, of course, is that hearing children see those gestures as part of a linguistic system that includes speech, whereas the deaf children see the gestures on their own. And this difference makes a big difference. Hearing children use gesture as their parents do, as part of a communication system that is fully integrated with speech (cf. McNeill, 1992). In contrast, deaf children transform the gestures their hearing parents provide them with, fashioning those gestures into a language-like system. It is this transformation process that best illustrates the fact that children are not passive recipients of the systems they use to communicate — they construct them and can use their hands to do so.

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