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How our hands help us learn

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When people talk they gesture, and those gestures often reflect thoughts not expressed in their words. In this sense, gesture and the speech it accompanies can mismatch. Gesture–speech 'mismatches' are found when learners are on the verge of making progress on a task – when they are ready to learn. Moreover, mismatches provide insight into the mental processes that characterize learners when in this transitional state. Gesture is not just handwaving – it reflects how we think. However, evidence is mounting that gesture goes beyond reflecting our thoughts and can have a hand in changing those thoughts. We consider two ways in which gesture could change the course of learning: indirectly by influencing learning environments or directly by influencing learners themselves.

Introduction

We know a great deal about the stages children pass through as they go from knowing less to knowing more. But we understand very little about *how* these changes take place, that is, about the mechanisms responsible for knowledge change. An excellent place to begin an exploration of the mechanisms underlying change is at points of transition – moments when a learner is on the verge of change.

Much recent research suggests that the gestures people produce as they explain a task reflect whether or not they are in transition with respect to that task. We begin this review by describing this evidence, showing that gesture reliably indexes transitional moments. However, there is new evidence suggesting that gesture could be more than just an index of change – it might be part of the *process* of change. We consider two non-mutually exclusive possibilities.

First, gesture could contribute to knowledge change through its communicative effects. If our gestures reflect the state of our knowledge, they have the potential to signal to others that we are at a transitional point (akin to Vygotsky's 'zone of proximal development' [1]). If listeners are sensitive to this signal, they might, as a consequence, change the way they interact with us. In this way, we can shape our learning environment just by moving our hands.

Second, gesture can contribute to knowledge change through its cognitive effects. Externalizing our thoughts can save cognitive effort that we can then put to more effective use [2]. For example, writing down a math problem can reduce cognitive effort, thereby freeing up resources that can then be used to solve the problem. In the same way, gesture can externalize ideas and thus has the potential to affect learning by influencing learners directly.

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Gesture is associated with learning

Nonverbal communication encompasses a wide-ranging array of behaviors – the environments we create, the distance we establish between ourselves and our listeners, whether we move our bodies, make eye contact, or raise our voices, all collaborate to send messages. These messages, although clearly important in framing a conversation, are not typically considered to be part of the conversation itself. Indeed, the traditional view of communication is that it is divided into content-filled verbal and affect-filled nonverbal components. Kendon [3] was among the first to challenge this view, arguing that at least one form of nonverbal behavior – gesture – cannot be separated from the content of conversation. In fact, the gestures we produce as we talk are tightly intertwined with that talk in timing, meaning and function [4]. To ignore gesture is to ignore part of the conversation.

This review focuses on the gestures that speakers produce spontaneously along with their speech, often called 'illustrators' [5]. These gestures differ from 'emblems', which have conventional forms and meanings (e.g. *thumbs-up*, *okay*, *shush*). Illustrators participate in communication but are *not* part of a codified system. They are thus free to take on forms that speech does not assume.

The relationship between gesture and speech predicts readiness to learn

The gestures that accompany speech encode meaning differently from speech [3,4,6]. Gesture relies on visual and mimetic imagery to convey an idea holistically, whereas speech conveys meaning discretely, relying on codified words and grammatical devices. Nonetheless, the information conveyed in gesture and in speech can overlap a great deal. Consider, for example, a child asked first whether the amount of water in two identical glasses is the same, and then whether the amount of water in one of the glasses changes after it is poured into a low, wide dish. The child says that the amounts of water are initially the same but differ after the pouring transformation – the child is a non-conserver. When asked to explain this answer, the child focuses on the height of the water in both speech and gesture, saying '*it's different because this one's low and that one's tall*', while gesturing the height of the water in the dish and then in the glass (Figure 1a). The child thus conveys the same information in gesture and speech: a gesture–speech match [7].

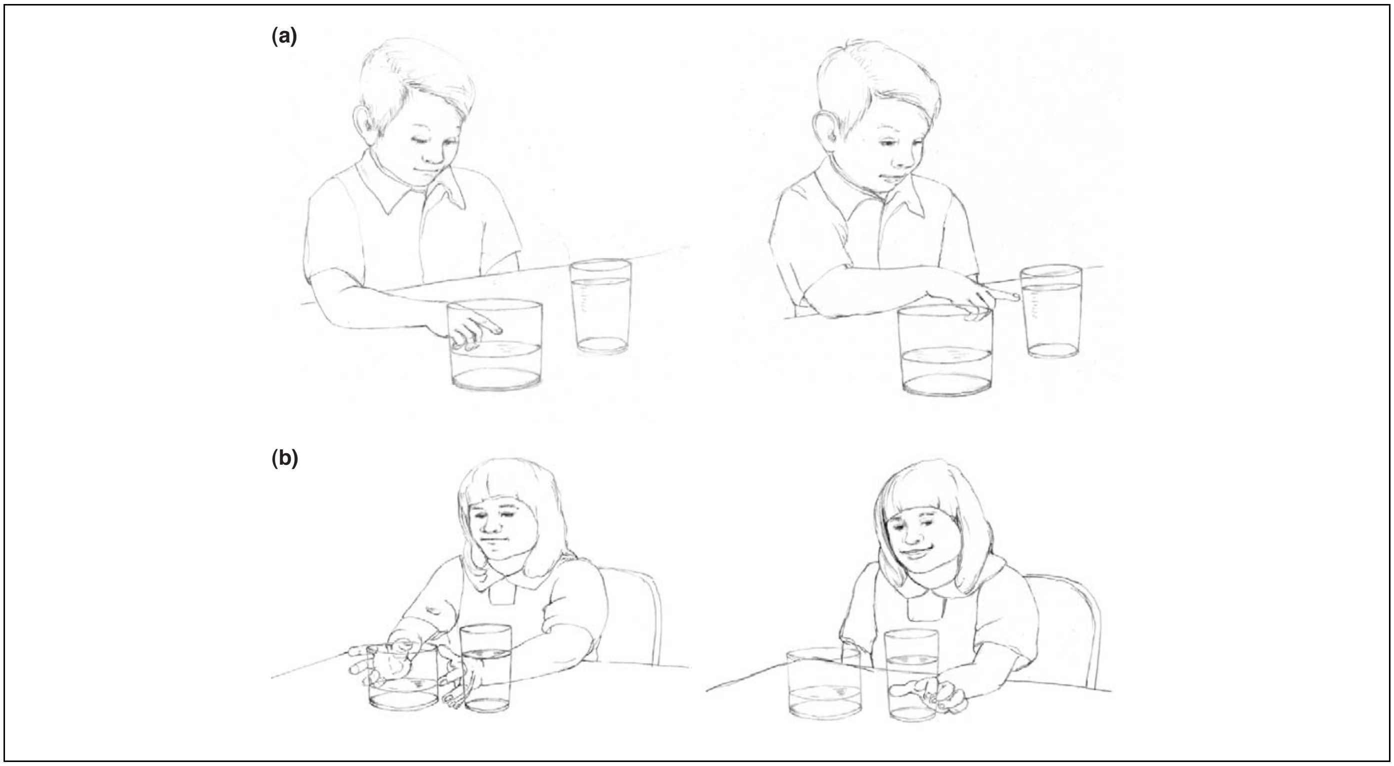

Figure 1. Examples of gestures that match and mismatch speech. The children are explaining why they think the amount of water is different in the two containers. Both say that the amount is different because the water level is lower in one container than the other. **(a)** The boy conveys the *same* information in gesture (he indicates the height of the water in each container) – he has produced a gesture–speech match. **(b)** The girl conveys *different* information in gesture (she indicates the width of each container) – she has produced a gesture–speech mismatch. Drawings by Linda Huff. Reprinted from Ref. [6] by permission of The Belknap Press of Harvard University Press © 2003.

There are, however, times when gesture conveys different information from speech. Consider another child (also a non-conserver) who gives the same explanation as the first child in speech but a different explanation in gesture. She produces a two-handed gesture representing the width of the dish, followed by a narrower one-handed gesture representing the width of the glass (Figure 1b). This child focuses on height in speech but width in gesture. She has produced a gesture–speech mismatch [7].

Children who produce mismatches on a task have information relevant to solving the task at their fingertips. The child in Figure 1b has noticed (albeit not consciously) that the dish is short and wide but the glass is tall and narrow, a potentially important insight into conservation. Such a child might therefore be particularly receptive to instruction in conservation. Indeed, when non-conservers are given instruction, the children who produce gesture–speech mismatches before that instruction are more likely to make progress on the task than children who produce matches [7]. This phenomenon is robust, found in learners of all ages on a variety of tasks taught by an experimenter (5- to 9-year-olds learning a balance task [8]; 9- to 10-year-olds learning a math task [9,10]; adults learning a gears task [11]), or learned in relatively naturalistic situations (toddlers learning their first word combinations [12,13]; school-aged children learning a mathematical concept from a teacher [14]; Figure 2).

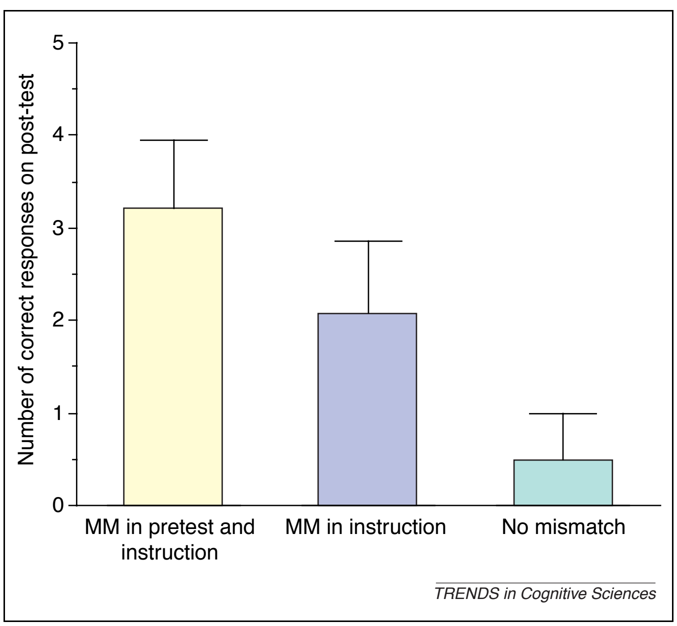

Figure 2. Data from a study of school children learning a mathematical concept from a teacher [14]. Plotted are the mean number of correct responses (with standard errors) that children produced on the post-test after instruction. On the horizontal axis, children are classified according to whether they produced mismatches (MM) before and during instruction (MM in pretest and instruction), only during instruction (MM in instruction), or not at all (No mismatch). Children who produce mismatches during the pretest and/or instruction phases are more likely to learn than children who do not produce mismatches. Data from [14].

Why do gesture–speech mismatches predict openness to instruction?

A speaker who produces a mismatch is expressing two ideas – one in speech and another in gesture. Importantly, it doesn't seem to matter whether those ideas are right or wrong. Children who produce two incorrect ideas, one in speech and one in gesture, are as likely to learn as children who produce an incorrect idea in speech but a correct idea in gesture [9]. Entertaining two ideas on a single problem could lead to cognitive instability, which, in turn, could lead to change.

If mismatches do indeed reflect the simultaneous activation of two ideas, a task known to encourage the activation of two ideas ought to evoke mismatches. The Tower of Hanoi is a well-studied puzzle that both adults and children solve by activating two ideas (a subroutine and an alternative path) at theoretically defined choice points [15–18]. We might therefore expect mismatches to occur at just these points – and, in fact, they do. When asked to explain how they solved the puzzle, both adults and children produce more gesture–speech mismatches – explanations in which speech conveys one path and gesture another – at choice points than at non-choice points [19]. Mismatches thus occur at points known to activate two strategies.

We can also test this idea from the opposite direction. We can select a situation known to elicit gesture–speech mismatches and explore whether two ideas are activated simultaneously in this situation. We can select, for example, a group of children who routinely produce gesture–speech mismatches when asked to explain their solutions to a set of math problems. We then determine whether these children activate two strategies when solving (but not explaining) the same math problems. The children are asked to remember a list of words while at the same time solving the math problems. If the children are activating two strategies on these problems, they should be working hard to solve them and should therefore remember relatively few words. And they do – indeed, they remember fewer words than children who never produce mismatches when explaining problems of this type; these children are presumably activating only one strategy when they solve the problems [20]. Mismatch seems to reflect the simultaneous activation of two ideas.

Is the information found in gesture in a mismatch unique to gesture?

When speakers produce a mismatch, the information conveyed in gesture is, by definition, not found in the accompanying speech. The child in Figure 1b, for example, conveys width information in gesture but not in speech. But perhaps this child, on the very next problem, describes the widths of the containers in speech; width information is then accessible to both gesture and speech, albeit not simultaneously. Alternatively, the information found in gesture in a mismatch might be accessible *only* to gesture; if so, the child would not be able to talk about the widths of the containers on any of the problems.

The second alternative turns out to be the case, at least in children learning mathematical equivalence – children who convey a particular strategy in gesture in a mismatch on one math problem generally do not convey that strategy in speech on *any* problems [21]. What this means is that children who produce mismatches have information in their repertoires that they know but cannot articulate. It also means that, as listeners, if we want to know that the children have this information in their repertoires, we need to pay attention to their gestures as well as their words. The fact that gesture conveys information not found in speech paves the way for it to play its own role in communication.

Gesture as a mechanism of change through its communicative effects

The hypothesis here is simple: (1) children reveal information about their cognitive status through their gestures; (2) people glean information from those gestures and alter their input to the children accordingly; (3) children profit from this altered input. We have reviewed evidence for the first point. The next question is whether people, teachers in particular, glean information from the gestures children produce and modify their instruction in response.

There is evidence that the gestures that people produce when they talk communicate information to listeners in experimental situations (Box 1). However, for gesture to play a role in learning, listeners must be able to glean information from gesture in naturalistic interactions. We [22]

Box 1. Do gestures communicate?

Although there is little disagreement about whether gesture displays information, there is great disagreement about whether listeners take advantage of that information [31,32]. Gestures can have an impact on communication, but it is not always easy to see its effects – you have to know where to look.

People can glean information from gestures when those gestures are presented without speech, but unless the gestures are points, gesture conveys little information on its own [33,34]. However, when we present gesture without speech, we are taking it out of its normal habitat; gesture is routinely produced with speech and needs to be interpreted within the framework provided by that speech.

Do we glean information from gesture when it accompanies speech? Krauss and colleagues [35] find that allowing listeners to see a speaker's gestures does *not* increase accuracy. Others find that accuracy is enhanced [36–39]. However, in all of these studies, gesture conveys the same information as speech. If the speech is easy to comprehend, gesture has little work to do. And if gesture improves accuracy, it might be doing so by drawing attention to speech, not by imparting information on its own.

The best place to explore whether gesture can impart information to listeners is in gesture–speech mismatches – instances where gesture conveys information *not* found in speech. If listeners report this information, they must be gleaning it from gesture – there is nowhere else to get it from.

McNeill and his colleagues [40] asked adults to retell a story told by a narrator performing a choreographed program of mismatching gestures. The narrator says, '*he comes out the bottom of the pipe*', while bouncing his hand up and down – a verbal statement that contains no mention of how the act was performed, accompanied by a gesture that does convey the up-and-down manner. The adult retelling the story resolves the mismatch by inventing a staircase. She says, '*and then goes down stairs*', while producing a mannerless gesture, a dropping straight-down motion. The adult not only picked up information conveyed uniquely in gesture (the bouncing manner) but also incorporated it into her speech. Information conveyed in gesture *is* noticed but not necessarily tagged as coming from gesture.

Listeners can also glean information from gesture in naturally produced mismatches, whether they witness the mismatches as third-party observers [41–44] or as participants [22]. Indeed, even children can pick up information conveyed in gesture (but not speech) in a mismatch [45,46]. Gestures not only display information, they can also, under the right circumstances, impart that information to listeners.

therefore observed teachers interacting with students. Teachers were asked to watch children explaining how they solved a series of math problems (no mention was made of gesture). The teachers then instructed each child individually. All of the teachers, at times, picked up on information that their students produced in gesture and *not* in speech, often translating that information into their own speech [22].

The teachers thus gleaned information from their students' gestures. But did they change their instruction as a result? Interestingly, the teachers gave different types of instruction to children who produced mismatches than to children who produced only matches. They used more different types of spoken strategies and more of their own gesture–speech mismatches when teaching children who produced mismatches [14]. And, as shown in Figure 2, children who produced mismatches learned. The children might have learned simply because they were ready to learn. However, the teachers' adjustments might also have contributed to the process. To find out, we gave children instruction based on the teachers' spontaneous adjustments and found that one aspect of their instruction – gesture–speech mismatch – did, in fact, promote learning (Box 2).

A conversation thus seems to take place in gesture alongside the conversation in speech: children use their hands to reveal their cognitive state to their listeners who, in turn, use their hands to provide instruction that promotes learning.

Gesture as a mechanism of change through its cognitive effects

Gesture could also play a role in learning, not indirectly through others, but directly by affecting learners themselves. Indeed, including gesture in instruction might promote learning because it encourages learners to produce gestures of their own. Adults mimic nonverbal behaviors that their conversational partners produce [23], and even infants imitate nonverbal behaviors modeled by an experimenter [24]. It would therefore not be surprising if school-aged children were to imitate the gestures that their teachers produce. Our current work suggests not only that they do but also that children who do gesture are more likely to succeed after instruction than children who do not [25]. Gesturing during instruction encourages children to produce gestures of their own, which, in turn, leads to learning.

But why? One possibility is that gesturing lightens cognitive load. To test this hypothesis, children and adults were asked to do two things at once: (1) explain how they solved a math problem, and (2) remember a list of words or letters. Both groups remembered more items when they gestured during their math explanations than when they did not gesture (Box 3). Gesturing saves speakers cognitive resources on the explanation task, permitting them to allocate more resources to the memory task.

But gesture might not be lightening the speaker's load. It might instead be *shifting* the load away from a verbal store onto a visuospatial store. The idea is that gesturing allows speakers to convey in gesture information that might otherwise have gone into a verbal store. Lightening the burden on the verbal store should make it easier to perform a verbal task simultaneously. If, however, the burden has in fact been shifted to a visuospatial store, it should be harder to simultaneously perform a spatial task (such as recalling the location of dots on a grid) when gesturing than when not gesturing. But gesturing continues to lighten the speaker's load even if the second task is a spatial one [26].

Box 2. The adjustments teachers make in response to children's gestures promote learning

Including gesture in instruction is, in general, good for learning [47–49]. But are the adjustments that teachers spontaneously make to learners in math tutorials particularly effective? To find out, we used these adjustments to design six different types of instruction. Following a pre-established script, an experimenter taught children either one correct problem-solving strategy in speech (*equalizer* on its own) or two correct strategies in speech (*equalizer* plus *add–subtract*). The experimenter also varied the relationship between speech and gesture: (a) no gesture; (b) matching gesture (*equalizer* in both speech and gesture for the one-strategy-in-speech group, plus *add–subtract* in both speech and gesture for the two-strategies-in-speech group); (c) mismatching gesture (*equalizer* in speech and *add–subtract* in gesture for the one-strategy-in-speech group, plus *add–subtract* in speech and *equalizer* in gesture for the two-strategies-in-speech group) [50]. Children who were taught one spoken strategy were more successful after instruction than children taught two spoken strategies; that is, teaching two strategies in speech was *not* good for learning. However, children who were taught with mismatching gestures were more successful after instruction than children taught with matching gestures or no gestures (Figure I). Teaching two strategies can promote learning but only when those strategies are taught simultaneously and in different modalities, perhaps because simultaneous gestural and verbal representational formats complement and reinforce one another in a way that sequential verbal formats do not.

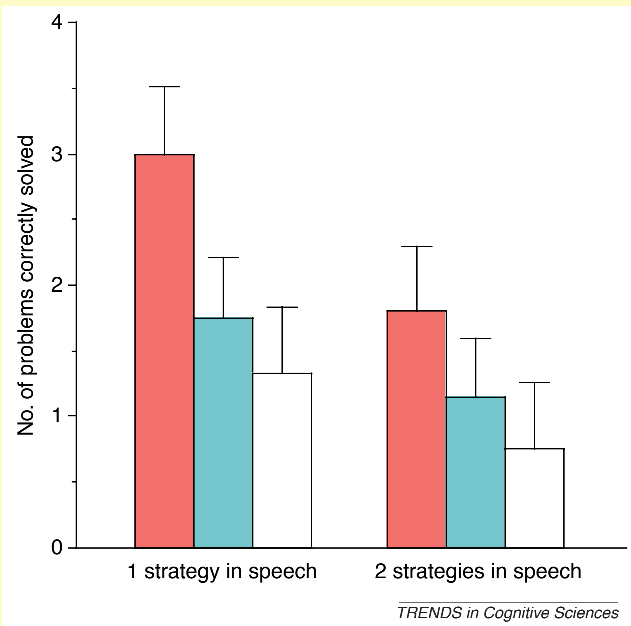

Figure I. Children taught with mismatches are more likely to learn than children taught with matches or no gesture. Plotted is the mean number of problems (with standard errors) that children solved correctly after receiving instruction that contained either one or two strategies in speech, and that was accompanied by no gesture (white bars), gesture matching the strategy in speech (green bars), or gesture mismatching the strategy in speech (red bars). Data from [50].

Box 3. Gesturing lightens cognitive load

The information that gesture conveys has an impact on the message listeners take from the communication (Box 1). However, speakers gesture even when they know their gestures cannot be seen [51,52]. For example, congenitally blind speakers gesture when talking to blind listeners [53]. Why? Might gesturing serve a function for speakers beyond the communicative function it serves for listeners?

Gesturing while speaking is likely to require motor planning, execution and coordination of two separate cognitive and motor systems [54,55]. If so, gesturing might be expected to increase speakers' cognitive load [56–58]. Alternatively, gesture and speech might form a single, integrated system in which the two modalities collaborate to convey meaning. Under this view, gesturing reduces demands on cognitive resources and frees capacity to perform other tasks.

To determine the impact of gesturing on speakers' cognitive load, children and adults were asked to explain how they solved a math problem and, at the same time, remember a list of words (children) or letters (adults). On some problems, speakers were permitted to move their hands freely. On others, they were requested to keep their hands still. If gesturing increases cognitive load, gesturing while explaining the math problems should take away from the resources available for remembering [59]. Memory should then be *worse* when speakers 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 speakers gesture than when they do not. The data in Figure I suggest that gesturing reduces cognitive load for both children and adults [60].

There is an alternative, however. Asking speakers not to gesture is, in effect, asking them to do another task, which could add to cognitive load. Being forced not to gesture might be hurting memory. To resolve this issue, we turn to a subset of adults who chose not to gesture on some of the problems on which they were allowed to move their hands. If being instructed not to gesture is itself a cognitive load, speakers should remember fewer items when instructed not to gesture, but not when they *choose* not to gesture. If, however, not gesturing constitutes the load, speakers should remember fewer items when they refrain from gesturing whether by instruction or by choice. The data in Figure II suggest that being forced not to gesture is no different from choosing not to gesture. Gesturing can indeed free speakers' cognitive resources.

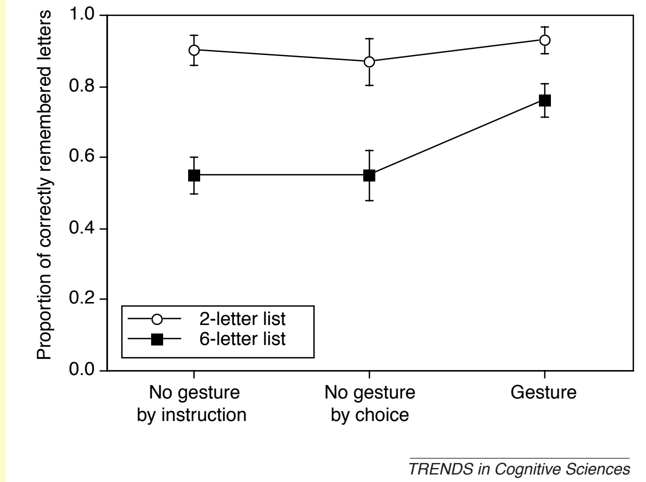

Figure II. Choosing not to gesture is no different from being forced not to gesture. Shown is the proportion of correctly remembered letters for adults who chose not to gesture on some of their explanations on the math task (see Fig. Ib). The adults remembered more of the longer memory-taxing lists when gesturing on the math task than when not gesturing, either by choice or by instruction. Error bars indicate standard errors. Data from [60].

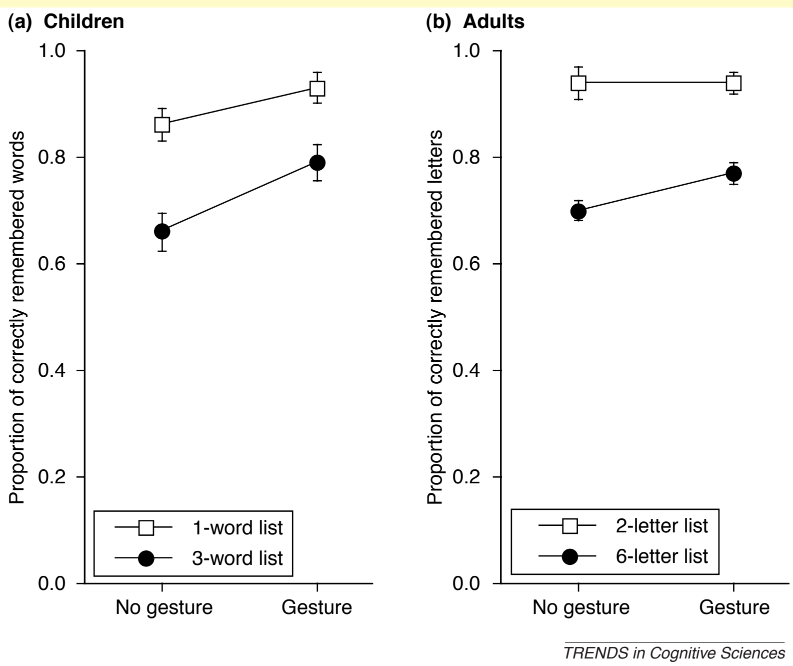

Figure I. Children and adults remember more when gesturing than when not gesturing. Shown is the proportion of correctly remembered words and letters in short lists (open symbols) and in longer lists (filled symbols) that tax memory. (a) Children and (b) adults performed the memory task while concurrently explaining their solutions to a math problem. Error bars indicate standard errors. Data from [60].

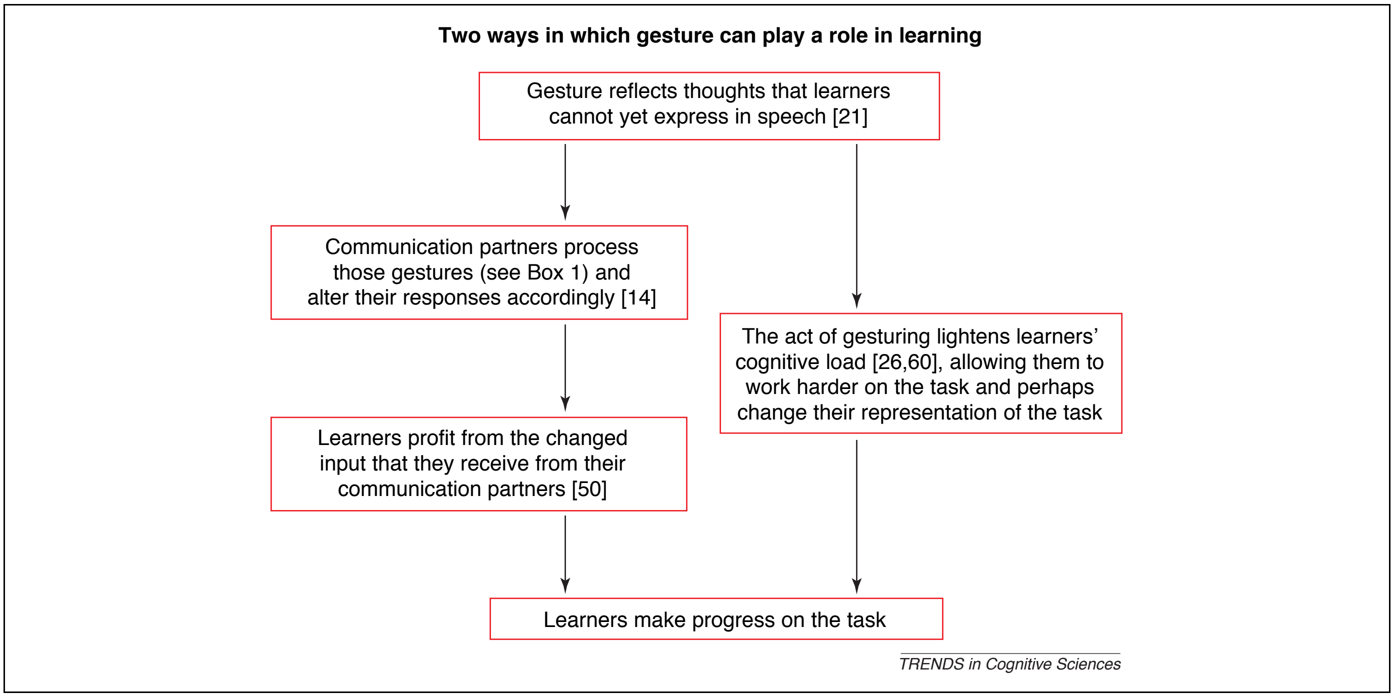

Figure 3. Schematic depiction of two ways in which gesture can participate in the mechanism of learning, either through the altered responses of a communication partner (left pathway), or by lightening the cognitive load of the learner (right pathway).

Perhaps gesturing lightens a speaker's load because it is a motor activity that energizes the system [27,28]. If so, it should only matter *that* a speaker gestures, not *what* the speaker gestures. But the number of items that speakers remember depends on the meaning conveyed by gesture – speakers remember more items when their gestures convey the same information as their speech (one message) than when their gestures convey different information (two messages). Gesture's content thus determines demands on working memory, suggesting that gesture confers its benefits, at least in part, through its representational properties.

Conclusions

Gesture provides insight into a speaker's thoughts. This window onto the mind is particularly useful when speakers are in a transitional state simply because, at these transitional moments, gesture can reveal thoughts that speakers do not express in their speech. However, as we have seen here, gesture does more than reveal thoughts – it plays a role in changing those thoughts (see Figure 3). It does so by signaling to listeners that the speaker is in a transitional state, thereby allowing listeners to calibrate their input to that state. It also changes thought more directly by freeing cognitive resources, thereby allowing the speaker to invest more effort in the task at hand.

The main question for future research (see also Box 4) is: What makes gesture such an effective learning tool? There are several possibilities. First, gesture is based on a different representational format from speech. Whereas speech is segmented and linear, gesture can convey several pieces of information all at once. At a certain point in acquiring a concept, it might be easier to understand, and to convey, novel information in the visuospatial medium offered by gesture than in the verbal medium offered by speech.

Second, gesture is not explicitly acknowledged. As a result, gesture can allow speakers to introduce into their repertoires novel ideas not entirely consistent with their current beliefs, without inviting challenge from a listener – indeed, without inviting challenge from their own self-monitoring systems. Gesture might allow ideas to slip into the system simply because it is not the focus of attention. Once in, those new ideas could catalyze change.

Third, gesture helps to ground words in the world. Deictic gestures point out objects and actions in space and thus provide a context for the words they accompany [29,30].

Box 4. Questions for future research

- Most of the work exploring gesture's role in talking and thinking has involved tasks that have a spatial component. Does gesture play the same role in nonspatial tasks? For example, do new ideas appear in gesture before they appear in speech in nonspatial, in addition to spatial, tasks? Does gesture lighten cognitive load in nonspatial tasks, as it does in spatial tasks?
- Most of the work exploring gesture's role in learning has involved children. But speakers of all ages gesture. Moreover, gesture seems to lighten cognitive load for adults as well as children. Does gesture play the same role in learning in adults as it does in children?
- Do individuals differ in the quantity and quality of the gesture they *produce*? Do they differ in how well they *understand* gesture? Are the two abilities related?
- Does gesture play different roles in communication or in cognition in cultures that are more and less tolerant of its use in spontaneous talk?
- Conventional sign language involves the same brain areas and networks as spoken language. Do the spontaneous gestures that accompany talk engage these same areas and networks?
- Do signers gesture and, if so, can those gestures convey information that is different from the signs that accompany them? In other words, do signers produce gesture–sign mismatches?

Gestures might, as a result, make it easier to understand words and also to produce them.

Whatever the process, there is ample evidence that the spontaneous gestures we produce when we talk reflect our thoughts – often thoughts not conveyed in our speech. Moreover, evidence is mounting that gesture goes well beyond reflecting our thoughts, to playing a role in shaping them.

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