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# The Mind Hidden in Our Hands

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**Abstract**

Our hands are always with us and are used for communication all over the world. When children do *not* have an established language model to learn from, they use their hands to gesture, and these gestures take on the forms of language. In this role, the hands reveal the fundamental properties of the mind that give shape to language. When children do learn an established language, they again use their hands to gesture. These gestures do *not* look like language but form an integrated system with language. In this role, the hands can convey ideas not found in the language they accompany. In both contexts, gesture provides a clear view of the mind hidden in our hands.

*Keywords:* Homesign; Language emergence; Gesture; Learning; Resilience

## 1. Introduction

Imagine a child who has never seen or heard language. How would this child communicate? The short answer is that the child would invent a language. A deaf child who cannot learn spoken language and has not been exposed to sign language nevertheless communicates and does so using gesture. These gestures, known as *homesign*, take on many of the forms and functions of language. The properties of language found in homesign do not need to be

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handed down from generation to generation but rather can be reinvented *de novo*. They are the resilient properties of language that all children, deaf or hearing, come to language learning ready to develop.

But most children do learn language from a linguistic model. However, they also use their hands to gesture. These gestures co-occur with speech (or sign if the child is learning a sign language) and are integrated into the language system they accompany. In other words, they do not form a linguistic system of their own. Nevertheless, the gestures are not mere hand-waving. They convey substantive ideas, and, importantly, those ideas are *not* always the same as the ideas displayed in the accompanying speech (or sign). The gestures can thus offer a view of the mind that differs from the view we get from speech or sign. The mismatch between the information conveyed in gesture and the information conveyed in speech or sign turns out to signal openness to change. Learners whose gestures mismatch their speech or sign on a task are more ready to learn that task than learners whose gestures match. Not only do these co-language gestures reflect what is on a learner's mind and their openness to change, but they can also play a role in changing the learner's mind.

Gesture is versatile in form and function. I begin by examining homesign gestures, which take on the primary burden of communication. In taking on the function of language, homesign also takes on its discrete and categorical form. Homesign is not handed down from one set of language users to another but is instead invented anew by each child. As a result, homesign reveals the fundamental properties of the mind that give shape to language. I then examine co-speech and co-sign gestures, which do not communicate on their own but do so in conjunction with the language they accompany. The form these gestures take is continuous and imagistic, and thus differs from the form of language. But homesign gesture and co-language gesture are comparable in one important respect—they both reveal parts of our minds that are hidden in our hands.

## 2. Speaking with our hands: When gesture becomes language

### *2.1. As long as there are humans, there will be language*

Let us imagine a far-fetched scenario in which all forms of language (spoken, signed, written) are wiped out, as is our knowledge of these forms, but everything else about us remains. Would we reinvent language? If so, would it look like human language as we know it? If language is simply a tradition handed down from generation to generation, then there is no guarantee that we would recreate it. And even if we did, the system we invent might look completely different from the system we have now. But if language is as it is because of the way humans structure their communication, we would not only reinvent language, but the language would have many of the characteristics of today's languages. As it turns out, our hands offer an answer to this question, but in order to see how, we need a little background.

The first background point is that language is not restricted to speech—deaf individuals use sign language as their primary means of communication, and sign languages display the essential components of human language (see Goldin-Meadow & Brentari, 2017, for dis-

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cussion). Second, deaf children who are exposed to sign language from birth by their deaf parents learn that language at the same pace as hearing children exposed to spoken language (Lillo-Martin, 1999; Newport & Meier, 1985). Third, most deaf children are born to hearing parents, who typically do not know a sign language and do not always put their children in situations where they would be exposed to an established sign language. If such a child is unable to learn spoken language naturally (as most profoundly deaf children are), the child will not have a model from an established language to learn from. In this sense, this child is living the far-fetched scenario described at the beginning of this section—surrounded by the modern world but without a learnable language. What does the child do? Children use their hands to fashion a language of *homesign* gestures from scratch (Begby, 2017; Botha, 2007; Frishberg, 1987; Goldin-Meadow, 2003a; Hill, Lillo-Martin, & Wood, 2018; Morford, 2002; Richie, Yang, & Coppola, 2014; Torigoe & Takei, 2002).

Homesign has many (but not all) of the properties found in natural language (Goldin-Meadow, 2020a; see Table 1 for a list of properties in homesign and citations). Although the manual modality lends itself to imagistic representation, allowing pictures to be drawn in the air, homesigners do not take full advantage of this property. Instead, they break events into small units, each represented by a gesture, and then string those gestures together. For example, rather than miming picking up and eating an apple (which would easily communicate apple-eating), an American homesigner points at an apple, produces an *eat* gesture (fingers touching the thumb while jabbing at the mouth), and then points at himself, thus creating a gesture sentence.

Importantly, when the homesigner strings gestures together, those gestures tend to follow a consistent ordering, even though the ordering is not essential for the sentence to be understood. It is quite clear from the context that the child is doing the eating, not the apple. The ordering in the gesture sentence is based on the semantic roles that the referents of the gestures play in the event described by the sentence; in this case, *apple* = patient, *eat* = action, *I* = agent (Goldin-Meadow & Mylander, 1984). Note that this ordering (patient-action-agent) is not the canonical order found in English (which is *agent-action-patient* = *I eat apple)*, the spoken language that surrounds this particular homesigner. Homesigners' gesture sentences are patterned and are generated by a combinatorial and productive system (Goldin-Meadow & Yang, 2017). The productivity found in homesign gesture sentences is comparable to the productivity found in spoken sentences produced by young hearing children—and, importantly, is greater than the productivity found in sign sentences produced by Nim Chimpsky (Yang, 2013). Nim is a chimpanzee who was taught signs, but his sentences are better described as rotely recalled rather than productive (Terrace, Petitto, Sanders, & Bever, 1979).

Another property found in all natural languages and also found in homesign is hierarchical structure. For example, homesigners refer to entities by pointing at that entity (a demonstrative, *that*) or by producing an iconic gesture referring, not to a particular entity, but to its class (a noun, *bird*). Homesigners combine these gestures to form larger, multi-gesture nominal constituents (*that bird*), which serve the same semantic and syntactic functions as demonstrative or noun gestures used on their own. The larger unit substitutes for the smaller units in homesign and thus functions as a complex noun phrase embedded under a sentence node––[[point at bird-BIRD] PEDAL] = *that bird pedals* to describe a picture of a bird riding a

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Table 1
Resilient properties of language

| The Resilient Property | As Instantiated in Homesign Systems | Citations (Number, Nationality, Age of Participants [Child/Adult]) |
|---|---|---|
| **Words** | | |
| Stability | Sign forms are stable and do not change capriciously with changing situations | Goldin-Meadow, Butcher, Mylander, and Dodge (1994) (one U.S. child homesigner child and his hearing mother) |
| Paradigms | Signs consist of smaller parts that can be recombined to produce new signs with different meanings | Goldin-Meadow et al. (1995; four U.S. child homesigners and their hearing mothers), Goldin-Meadow et al. (2007; four U.S. and four Chinese child homesigners and their hearing mothers); Abner, Namboodiripad, Spaepen, and Goldin-Meadow (2021; four Nicaraguan child homesigners); Horton, Goldin-Meadow, Coppola, Senghas, and Brentari (2015; four Nicaraguan adult homesigners, eight Nicaraguan Sign Language [NSL] adult signers, four ASL, and four LIS [i.e., Italian Sign Language] adult signers, four U.S. adult hearing English-speakers and four adult Italian hearing Italian-speakers) |
| Categories | The parts of signs are composed of a limited set of forms, each associated with a particular meaning | Goldin-Meadow et al. (1995; see above) |
| Arbitrariness | Pairings between sign forms and meanings can have arbitrary aspects, albeit within an iconic framework | Goldin-Meadow et al. (2007; see above) |
| Grammatical functions | Signs are differentiated by the grammatical functions they serve (noun, verb, subject) | Goldin-Meadow et al. (1994; see above); Coppola and Newport (2005; three Nicaraguan adult homesigners); Hunsicker and Goldin-Meadow (2013; one U.S. child homesigner); Abner et al. (2019; four Nicaraguan adult homesigners, 24 NSL adult signers, five ASL [American Sign Language] adult signers)) |
| Words for relational concepts | Particular signs are used to signal past, future, uncertainty and to mark illocutionary force | Morford and Goldin-Meadow (1997; four U.S. child homesigners and 18 U.S. hearing child English-speakers); Franklin, Giannakidou, and Goldin-Meadow (2011; one U.S. child homesigner) |
| **Sentences** | | |
| Underlying frames | Predicate frames underlie sign sentences | Goldin-Meadow (1985; 10 U.S. child homesigners) |
| Deletion | Consistent production and deletion of signs within a sentence mark particular thematic roles | Feldman, Goldin-Meadow, and Gleitman (1978; six U.S. child homesigners); Goldin-Meadow, Namboodiripad, et al. (2015; four Turkish and four U.S. child homesigners) |

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Table 1
(Continued)

| The Resilient Property | As Instantiated in Homesign Systems | Citations (Number, Nationality, Age of Participants [Child/Adult]) |
|---|---|---|
| Word order | Consistent orderings of signs within a sentence mark particular thematic roles | Goldin-Meadow and Feldman (1977; six U.S. child homesigners); Goldin-Meadow and Mylander (1984; 10 U.S. child homesigners) |
| Inflections | Consistent inflections on signs mark particular thematic roles | Goldin-Meadow et al. (1994; see above); Goldin-Meadow, Brentari, et al. (2015; four Nicaraguan adult homesigners, eight Nicaraguan adult NSL signers, three U.S. adult ASL signers); Rissman and Goldin-Meadow (2017; one U.S. child homesigner) |
| Recursion | Complex sign sentences are created by recursion | Goldin-Meadow (1982; six U.S. child homesigners); Goldin-Meadow and Mylander (1998; four U.S. and four Chinese child homesigners and their hearing mothers); Flaherty et al. (2021; seven Nicaraguan and four U.S. child homesigners and their hearing families) |
| Redundancy reduction | Redundancy is systematically reduced in the surface of complex sign sentences | Goldin-Meadow (1987; one U.S. child homesigner) |
| Hierarchical structure | Complex noun phrases are embedded within larger constituents | Hunsicker and Goldin-Meadow (2012; one U.S. child homesigner and his hearing mother); Flaherty et al. (2021; see above) |
| Categorizing events | Universal constraints on how languages categorize events involving tools | Rissman, Horton, and Goldin-Meadow (2023; 10 homesigners in five countries, Guatemala, Nicaragua, the United States, Taiwan, Turkey) |
| Motion events | U.S. and Chinese homesigners use the same structures to convey the central elements of a motion event. U.S. and Chinese hearing children express motion events differently, following the structures in the language they are learning | Four U.S. and four Chinese homesigners; four U.S. children learning English, four Chinese children learning Mandarin |
| Symmetrical versus reciprocal construals in verbs | Symmetrical verbs are mirrored; reciprocal verbs are not | Gleitman et al. (2019; four Nicaraguan adult homesigners, 23 adult NSL signers) |
| Marking agency and number on the verb | Agency and number marked simultaneously on one verb (homesign, NSL 1) or sequentially across verbs (NSL 2) | Brentari, Coppola, Horton, Senghas, and Goldin-Meadow (2024; four Nicaraguan adult homesigners, eight adult NSL signers) |

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Table 1
(Continued)

| The Resilient Property | As Instantiated in Homesign Systems | Citations (Number, Nationality, Age of Participants [Child/Adult]) |
|---|---|---|
| **Language Use** | | |
| Here-and-now talk | Signs are used to make requests, comments, and queries about the present | Goldin-Meadow and Mylander (1984; see above) |
| Displaced talk | Signs are used to communicate about the non-present, the past, future, and hypothetical | Butcher, Mylander, and Goldin-Meadow (1991; one U.S. child homesigner and his hearing mother; four U.S. child English-speakers); Morford and Goldin-Meadow (1997; see above) |
| Generics | Signs are used to make generic statements, particularly about animals | Goldin-Meadow et al. (2005; four U.S. and four Chinese child homesigners, eight U.S. child English-speakers, and eight Chinese child Mandarin-speakers) |
| Narrative | Signs are used to tell stories about self and others | Phillips, Goldin-Meadow, and Miller (2001; four U.S. and four Chinese child homesigners) |
| Self-talk | Signs are used to communicate with oneself | Goldin-Meadow (1993; one U.S. deaf homesginer) |
| Meta-language | Signs are used to refer to one's own and others' signs | Goldin-Meadow (1993; see above) |

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bicycle—a hierarchical structure (Flaherty, Hunsicker, & Goldin-Meadow, 2021; Hunsicker & Goldin-Meadow, 2012).

We see in the hands of the homesigning child the properties of mind that all children bring to language, properties that allow children to learn the language around them or to create a language if they are not exposed to one. These are the *resilient properties of language* (Goldin-Meadow, 1982, 2003a; see Table 1). Homesign also tells us that language is not an accident of history. As long as there are humans, there will be language.

### *2.2. The child creates sentence structure in homesign*

But maybe it is not the child who is inventing homesign. Everyone gestures when they talk (Goldin-Meadow, 2003b; Kendon, 2004; McNeill, 1992), including the homesigners' hearing parents. Maybe the parents invented the gestures, which were then copied by their children. If so, it is not the children who invented the homesign system—it is the parents. There is, however, no evidence for this hypothesis. When we compare the parents' gestures (the ones they produce while talking to their children) to the homesigners' gestures, we find that they do *not* look the same. For example, the homesigners produce more gesture strings than their parents and structure their strings differently from their parents (Goldin-Meadow & Mylander, 1984, 1998). As another example, the homesigners' gestures are composed of parts, each conveying a particular meaning; the meaning of the gesture is derived from the meanings of its parts. In other words, the homesigners' gestures have a morphological structure. Their parents' gestures do not (Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007; Goldin-Meadow, Mylander, & Butcher, 1995). Finally, almost all homesigners that have been studied produce complex nominal constituents in their gestures; their hearing parents do not (Flaherty et al., 2021).

The hearing parents do not provide a model for the language the homesigners create, but maybe they respond to their children's homesigns systematically and shape the language in that way. There is also no evidence for this hypothesis. The parents are no more likely to respond with approval, or with sequiturs, after a well-structured homesign sentence than after a poorly structured sentence (Goldin-Meadow & Mylander, 1984). Along the same lines, Carrigan and Coppola (2017) found that the hearing mothers of homesigners in Nicaragua have difficulty understanding their homesigners' signs. In fact, signers of American Sign Language (ASL) were better at understanding the homesigners' message than the hearing parents were. The hearing mothers' ability to understand homesign is not exerting a strong pressure on the structure of the system.

Homesigning children bring a great deal of structure to the linguistic systems they create. But they are not creating these systems in a vacuum. Just seeing hearing people gesture may inspire in the homesigning child the desire to communicate and to use their hands to do so. In addition, there is evidence that both U.S. and Chinese homesigners share the building blocks of their word-level structure with their hearing parents, raising the possibility that the children may have learned those forms from their parents' gestures; it is, however, important to point out that the children use the building blocks to construct structured gesture words; their parents do not (Goldin-Meadow et al., 2007). Finally, although there is no evidence

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that the homesigners' hearing parents selectively reinforce gesture sentences with particular orders, homesigners whose parents are particularly sensitive to the messages their children want to express may communicate more, and may develop more extensive systems, than homesigners whose parents are less sensitive. We are currently exploring this possibility in the original videotapes.

### *2.3. Watching language grow naturally over generations of users*

Children all over the globe invent homesigns (e.g., China—Goldin-Meadow & Mylander, 1998; Zheng & Goldin-Meadow, 2002; Turkey—Goldin-Meadow, Brentari, Coppola, Horton, & Senghas, 2015; Nicaragua—Flaherty et al., 2021), and those homesign systems contain properties that reflect the rudimentary structures of language. But homesigners are not likely to invent all aspects of a fully developed language on their own. In fact, all over the globe, homesign systems gain linguistic properties and turn into fully fledged sign languages as homesigners come together and communicate with one another on a daily basis (Brentari & Goldin-Meadow, 2017; Fusellier-Souza, 2006; Kegl, 1994; Kegl, Senghas, & Coppola, 1999). These linguistic properties may need to be handed down from generation to generation, that is, they may need to be fashioned by iterations of learners in order to emerge in a language.

We can explore these linguistic properties by looking at naturally occurring situations of language emergence. Luckily, just such a situation is taking place right now. Forty years ago, individual homesigners in Nicaragua were brought together for the very first time and began to fashion a sign language called Nicaraguan Sign Language, NSL. We see over this time period changes in the language introduced by different cohorts of signers. Homesigners started the process off. They create their systems individually; each homesigner produces a structured system of gestures but gets co-speech gestures back from their hearing relatives (more on these types of gestures later). In contrast, the first cohort of NSL signers created their systems together and are not only producers of the system but also receivers. Finally, all subsequent generations of NSL signers are learners; they enter the deaf community as children, learn NSL from their peers and, in the process, change the language.

By comparing Nicaraguan homesign to NSL in the different cohorts, we can separate linguistic properties into three types as a function of when they appear in this emerging language:

1. Linguistic properties that appear in homesign and are used by subsequent cohorts of NSL. These properties can be created by an individual who produces, but does not receive, a linguistic system. For example, homesigners and NSL signers use different verb forms to convey a symmetrical relation (two palms hitting one another to describe two people *high*-fiving) versus a reciprocal relation (one fist punching away from the body, followed by a second fist punching toward the body, to describe two people who are, in fact, *punching* each other *at the same time*). The symmetrical relation is conveyed using two *simultaneously* produced movements; the reciprocal relation is conveyed using two *sequentially* produced movements even though the two punches in the event were produced at the same time (Gleitman, Senghas, Flaherty, Coppola, &

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Goldin-Meadow, 2019). The distinction between symmetrical and reciprocal events is so central to human language that it can be invented *de novo* by individual homesigners and then picked up and incorporated into NSL.

2. Linguistic properties that appear in NSL Cohort 1 and all subsequent cohorts but not in homesign. These properties cannot be created by an individual and need communication between individuals to emerge. For example, in addition to using lexical verb forms to distinguish symmetrical and reciprocal relations, NSL Cohort 1 and subsequent cohorts also use different syntactic structures to distinguish symmetrical from reciprocal relations; homesigners do not (Gleitman et al., 2019).
3. Linguistic properties that appear in NSL Cohort 2 and beyond, but not in NSL Cohort 1 or homesign. These properties are only created when individuals learn language from a model. For example, NSL Cohort 2 has devices not only for referring to the agent but also for *backgrounding* it. Although Cohort 1 and homesign have devices that refer to the agent, they do not have ways to background it (Rissman et al., 2020). As a second example, Coppola and Senghas (2010) found that locative points (e.g., a point above the head to refer to a location above the head of a cat in a story) were produced by homesigners and NSL Cohorts 1 and 2. However, only Cohort 2 signers produced nominal points (e.g., a point to the left to refer to Tweety Bird, not to Tweety's location), suggesting that transmission is key to the emergence of this particular property in language. Language emergence in Nicaragua allows us to speculate about the conditions that have made language what it is today.

But language emergence under natural conditions is relatively uncontrolled. In order to exert some control over the conditions under which a communication system is created, researchers have asked hearing speakers to describe events using only their hands; in other words, to produce *silent gestures*. Interestingly, silent gesture is structured, but it does not take its structure from the gesturer's spoken language. For example, speakers of English, Spanish, Turkish, Chinese, Japanese, and Korean (Gibson et al., 2013; Goldin-Meadow, So, Ozyurek, & Mylander, 2008; Hall, Ferreira, & Mayberry, 2014; Hall, Mayberry, & Ferreira, 2013; Meir, Lifshitz, Ilkbasaran, & Padden, 2010; Meir et al., 2017) all use a subject-object-verb *gesture* order to describe an animate acting on an inanimate (e.g., a captain swinging a pail, gestured as *captain-pail-swing*), regardless of the typical word order in the gesturer's native spoken language.

Although silent gesture displays some properties of human language (e.g., word order), it does not display all of the properties of language and does not even display the full set of properties found in homesign. For example, homesigners often segment their motion gestures into components (a *curving* gesture representing a path, followed by a *wiggle* gesture representing manner of motion), whereas silent gesturers tend to produce one gesture representing both components simultaneously (fingers *wiggling* as they move along a *curved* path; Ozyurek, Furman, & Goldin-Meadow, 2015; see also Goldin-Meadow, 2015). Children, even those *not* exposed to an established language, may be better at creating language with their hands than adults, who have been using language all of their lives.

### 2.4. *Language is more resilient than number*

Language comes naturally to homesigners, suggesting that language is deeply entrenched in humans. Are other cognitive skills equally entrenched? Imagine that you ask a homesigner (it could even be an adult homesigner) whether one set of objects matches another set of objects. If you give the homesigner two sets that contain one, two, or three objects, he will solve the task flawlessly. But if you give him two sets that contain four or more objects, the homesigner will be approximately, but not exactly, correct—for example, he will at times match a set containing six objects with a set containing six objects, but at other times, he will match the set with sets containing five or seven objects. In other words, the adult homesigner will have trouble with large exact numbers, a key aspect of our numerical system (Spaepen, Coppola, Spelke, Carey, & Goldin-Meadow, 2011). Thus, even though homesigners use gesture to communicate about number, they do not always correctly match the number of items in a set to a target set when that target set is greater than three, nor do they consistently extend the correct number of fingers when communicating about sets greater than five. Even when integrated into a numerate society like Nicaragua, homesigners do not spontaneously develop representations of large exact numerosities.

Homesigners may not even be using their number gestures to refer to *sets*. If a homesigner holds up four fingers, he could be using that hand configuration to refer to a set of *four*. Alternatively, since the four fingers correspond one-to-one with the four objects in the set, the homesigner could be indicating each item individually, *one-one-one-one*, with no representation of the set itself. If the handshape is functioning as a label for the set, it should be no harder to remember a list containing large numbers (lots of fingers raised) than a list containing small numbers (fewer fingers raised). But if each finger of the handshape is used to index each item, remembering a list of large numbers (lots of fingers) is likely to be harder than remembering a list of small numbers (fewer fingers). This is precisely what Spaepen, Coppola, Flaherty, Spelke, and Goldin-Meadow (2013) found in memory span tasks conducted with adult homesigners in Nicaragua and with comparison groups of unschooled hearing Spanish speakers and deaf NSL signers. Homesigners were less likely to remember lists of number gestures with eight or nine fingers raised than lists of number gestures with four or five fingers raised; no such difference was found for NSL signers, who also were recalling handshapes with raised fingers. The difference was also not found in Spanish speakers' number words, which makes intuitive sense since speakers have no more trouble remembering a phone number with 8 and 9 in it than a phone number with 4 and 5 in it. Homesign gestures for numbers do not seem to be functioning as summaries of the cardinal values of the sets (*four*) but rather serve as indexes of items within a set (*one-one-one-one*). We learn from our hands that language can be created by a child, exact number cannot.

Homesigning gestures illustrate just how important structured communication is to humans. A child who has had no experience with language as we know it can nevertheless invent a structured communication system that has many (but not all) of the properties of human language. Homesign reveals the properties of human mind that structure language, not the other way around.

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When a child learns a language, that language will obviously influence the way the child *talks* (or signs) about things. But it could also influence the way the child *thinks* about things. Gesture has a role to play here too. Ideas that do not fit neatly into a language (either because the language makes it hard to express the idea, or because the speaker is unable to articulate the idea at that moment in time) can be expressed in gesture. Gesture can thus help all of us, including children, go beyond the language we speak (or sign), as we will see as we explore gestures produced along with language.

## 3. Thinking with our hands: When gesture accompanies language

Homesign tells us that the fundamental properties of thought are, in some sense, deeper than the languages we learn. We therefore should not expect language to reflect our thoughts perfectly. All of this opens the door to another vehicle for expressing thoughts that are not always easily accommodated by the languages we learn.

### *3.1. Hands reveal unspoken thoughts*

We communicate not only with language but also with our bodies. Much has been written about how our bodies convey our attitudes and feelings about ourselves, our listeners, and what we are saying (Argyle, 1975; Knapp, 1978; Wundt, 1900/1973). But our bodies and, in particular, our hands do more than reveal our feelings about the conversation—they make substantive contributions to the conversation itself. Season 4 of *The Crown* on Netflix shows Lady Diana getting a quick lesson on how to behave in royal society, including how to use—or not use—her hands when she speaks. Her teacher ties up her hands so she would not reveal her nervousness, uncertainty, and general lack of confidence. But by tying up Diana's hands, her teacher has also removed an important window onto her thoughts, a window that has the potential to display her cutting-edge ideas (which may have been exactly what the teacher and the royal family wanted).

#### *3.1.1. Our hands convey substantive information about our minds*

How do we know that our hands convey information? They could just be drawing attention to the speaker's words, which then do all of the work. The best way to tackle this question is to find instances where the information displayed in gesture is different from the information conveyed in speech. For example, when asked to prove that two molecules are stereoisomers, a chemistry student does not mention rotation in his words. But he rotates his hands during his explanation. This student might know (at least at an implicit level) that rotation is a key concept in identifying stereoisomers and might be ready to learn the concept—but only if his gestures are conveying meaningful information.

Ping et al. (2021) put this hypothesis to the test by giving college students a stereoisomer pretest and asking them to explain their solutions. The students were then given a brief lesson in stereoisomers and a posttest comparable to the pretest. The experimenters categorized each of the explanations the students gave on the pretest according to whether it was

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produced in speech and gesture, in speech alone, or in gesture alone, and used the categorized explanations to predict posttest performance. They found that conveying information relevant to stereoisomers in gesture alone on the pretest predicted success on the posttest—conveying relevant information in both gesture and speech or in speech alone on the pretest did not (Ping et al., 2021). It is only by considering the content of the students' gestures that we can predict their performance after the lesson—it is not whether or not a student gestures but what the student conveys with those gestures that matters.

Consider a 9-year-old child solving the math problem, $3 + 5 + 7 = \_\_ + 7$. She solves the problem incorrectly, adding up the 3, 5, and 7 on the left side of the equation, and puts 15 in the blank. At the same time, she produces a gesture—she puts one hand under the 7 on the right side of the equation and the other hand under the 7 on the left side of the equation. Despite the fact that she has solved the problem incorrectly, she noticed something important about the problem—that the same number appears on the right and left sides of the equation. Noticing this fact licenses adding up the two unique numbers on the left side of the equation, the 3 and the 5, adding them, and putting 8 in the blank (the correct answer). The student's hands, and only her hands, tell us that she has noticed these "equal addends." If she is now given a lesson in mathematical equivalence, she is likely to learn how to solve the problems—more likely than a child whose gestures point out the same numbers that she mentions in speech (i.e., point at the 3, 5, and 7 on the left side of the problem; Alibali & Goldin-Meadow, 1993; Perry, Church, & Goldin-Meadow, 1988). People who produce gesture–speech mismatches on a task are particularly ready to learn that task. People who produce only matches are not.

The stereoisomer example and the child's explanation of the math problem are instances of *mismatch* between gesture and speech, where gesture conveys information not found in speech. Gesture–speech mismatch is found in speakers of all ages and on a wide range of tasks—toddlers going through a spurt in the size of their vocabularies (Gershkoff-Stowe & Smith, 1997); preschoolers explaining a game (Evans & Rubin, 1979) or counting a set of objects (Alibali & DiRusso, 1999; Graham, 1999; Gunderson, Spaepen, Gibson, Goldin-Meadow, & Levine, 2015); children explaining science concepts (Crowder & Newman, 1993); children and adults discussing moral dilemmas (Church, Schonert-Reichl, Goodman, Kelly, & Ayman-Nolley, 1995) or explaining how they solved a logical puzzle, the Tower of Hanoi (TOH; Garber & Goldin-Meadow, 2002); adolescents predicting when rods of different materials and thicknesses will bend (Stone, Webb, & Mahootian, 1992); adults explaining how gears work (Perry & Elder, 1997; Schwartz & Black, 1996), narrating a cartoon story (Beattie & Shovelton, 1999; McNeill, 1992), or describing pictures of landscapes, abstract art, buildings, people, machines (Morrell-Samuels & Krauss, 1992; Rauscher, Krauss, & Chen, 1996) and problems involving constant change (Alibali, Bassok, Solomon, Syc, & Goldin-Meadow, 1999).

We have not, of course, tested whether gesture–speech mismatch predicts readiness to learn at all ages and on all tasks. However, the fact that mismatch is a reliable predictor in toddlers (Iverson & Goldin-Meadow, 2005), school-aged children (Church & Goldin-Meadow, 1986; Perry et al., 1988; Ping & Goldin-Meadow, 2008), and adults (Perry & Elder, 1997; Ping et al., 2021) and in learning language (Iverson & Goldin-Meadow, 2005), number (Gibson, Gunderson, Spaepen, Levine, & Goldin-Meadow, 2018), math (Alibali & Goldin-Meadow,

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1993; Perry et al. 1988), chemistry (Ping et al., 2021), the balance scale (Pine, Lufkin, & Messer, 2004), and conservation (Church & Goldin-Meadow, 1986) suggests that gesture–speech mismatch's reach is likely to be large.

*Why* do we gesture when we talk, and why does gesture so often convey information not found in that talk? Speakers use their hands when they talk in every known culture, no matter the language (Cooperrider, 2019; Feyereisen & de Lannoy, 1991). Individuals who were born blind and have never seen anyone gesture, move their hands just like sighted speakers do when they talk (Iverson & Goldin-Meadow, 1998), as do individuals who have lost their hands and gesture with a prosthesis (Maimon-Mor et al., 2020). Even signers, who use their hands for language (American Sign Language, British Sign Language, Chinese Sign Language, Israeli Sign Language, etc.), gesture when they sign (Emmorey, 1999; Lu & Goldin-Meadow, 2018; Sandler, 2009). Gesture is an essential human behavior because language is not in itself capable of capturing all of the ways that our minds think.

Language is rule-governed and packages information into categories. The language we speak forces us to convey information required by that language; for example, in a language like English, which requires plural markers, the speaker needs to indicate whether there is more than one item even if the number of items is not relevant to the message. The flip side of having ready-made categories is that it is easy to leave out information that does not fit neatly into those categories. What gesture does is allow us to fill in the picture with ideas that are hard to fit into the pre-packaged units language provides. Gesture can be used to tailor an imperfect language to the needs of both speaker and listener. That tailoring can come about either because the speaker does not have the ideas fully fleshed out, does not have the ability to express the idea in speech at that time, or perhaps because the speaker is uncomfortable expressing the idea in speech.

#### *3.1.2. Is the information we convey in gesture accessible to others?*

Can ordinary listeners who are not trained in gesture coding glean substantive information from gesture? If they cannot, gesture may reflect ideas not conveyed in speech, but those ideas will not become part of the conversation. There have been a variety of approaches to this question, which have all found that the contents of gesture are accessible to listeners. Cassell, McNeill, and McCullough (1999) created different types of gesture–speech mismatches and inserted them into a narration. Adults were asked to listen to and watch the narrator and then retell the story they heard. The adults not only picked up on the information conveyed uniquely in gesture, but they also translated that information into their own speech. For example, the narrator said, "and she whacks him one," while producing a punching gesture in the air. When the adult retold the story, she said "she punched Sylvester out," not realizing that the narrator never mentioned punching in his speech.

Broaders and Goldin-Meadow (2010) created mismatches to see whether information conveyed uniquely in gesture could lead child witnesses astray. Children saw a musician in their classrooms and later answered questions about the musician. The musician was *not* wearing a hat. When we asked a misleading question ("what color was the hat the musician was wearing?"), children frequently said that the musician *was* wearing a hat. Interestingly, they were just as likely to say the musician was wearing a hat when they heard a non-misleading

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question ("what else was he wearing"), combined with a misleading gesture (a *putting-on-hat* gesture), as they were when they heard the misleading question without gesture (Broaders & Goldin-Meadow, 2010). The children had clearly understood the interviewer's gestures and been swayed by them.

In a step toward a more naturalistic approach, Alibali, Flevares, and Goldin-Meadow (1997) took videos of naturally produced matching and mismatching responses on the mathematical equivalence task and asked adults to view the videos and describe the strategies that were mentioned in each explanation. The adults picked up on the problem-solving strategies conveyed uniquely in gesture and translated those strategies into their own speech (without noting that the strategies appeared only in gesture; see also Goldin-Meadow & Sandhofer, 1999; Goldin-Meadow, Kim, & Singer, 1999; Goldin-Meadow, Wein & Chang, 1992, for adult listeners; and Kelly & Church, 1997, 1998, for child listeners).

Finally, in a relatively natural teaching situation, Goldin-Meadow and Singer (2003) first asked a teacher to watch as we gave a 9- to 10-year-old student a mathematical equivalence pretest; we then asked the teacher to teach the student how to solve this type of problem. Each teacher saw children who produced at least one mismatch and children who produced no mismatches during the pretest. When it was their turn to teach the children, although they were not told who the matchers and the mismatchers were, the teachers used different teaching strategies for the two types of children. They gave more different strategies for solving the problem to the mismatchers than to the matchers, and they produced more of their own mismatches when teaching the mismatchers than the matchers (Goldin-Meadow & Singer, 2003). The teachers had read the children's gestures and adjusted their lessons accordingly. When gesture conveys unspoken thoughts, those thoughts are accessible to listeners of all ages, which means that they are part of the conversation.

### *3.2. Hands change minds*

Gesture not only reveals the contents of our minds; it can also change that content, in two ways—the gestures that others produce can change our minds, and the gestures that we ourselves produce can change our minds.

#### *3.2.1. Seeing others gesture*

Let us go back to the 9-year-old child whose hands tell us what she knows, even if she does not know she knows it. Since gesture can predict whether she is likely to learn the math task and is thus tied to her cognition, maybe we could use gesture to teach her math. In fact, many researchers have found that adding gesture to a lesson improves children's performance after the lesson (Carlson, Jacobs, Perry, & Church, 2014; Rueckert, Church, Avila, & Trejo, 2017; Valenzeno, Alibali, & Klatzky, 2003). In these studies, the gestures added to the spoken instruction conveyed the same information as the speech, thereby reinforcing the speech.

But gesture in instruction can promote learning even when it conveys different information from speech. Singer and Goldin-Meadow (2005) gave groups of 9- to 10-year-old children mathematical equivalence instruction containing the *equivalence* strategy in speech ("You need to make the two sides of the equation equal" for problems like $3 + 5 + 7 = \_\_ + 7$).

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One group of children received speech alone. One group received speech plus the *equivalence* strategy in gesture (a sweep under the left side of the equation, followed by a sweep under the right side). One group received speech plus a different strategy in gesture (points at the three numbers on the left side of the equation, followed by a take-away gesture under the 7 on the right side of the equation, the *add–subtract* strategy). Another group received two strategies in speech, *equivalence* and *add–subtract* and no gesture. The children who received two different strategies, one in speech and the other in gesture, performed best after instruction—significantly better than children who got *equivalence* and *add-strategy* entirely in speech, and children who got the same *equivalence* strategy in gesture and speech (Singer & Goldin-Meadow, 2005).

Interestingly, two different strategies, one in speech and a different one in gesture, work best as a lesson if the two strategies are produced simultaneously. Congdon et al. (2017) taught children mathematical equivalence using the *equivalence* strategy in speech. One group also received the *add–subtract* strategy in speech, produced sequentially with *equivalence*. The other two groups received the *add–subtract* strategy in gesture, produced either sequentially or simultaneously with the spoken *equivalence* strategy. Children did best on the posttest if they had received the gesture plus speech strategies simultaneously, significantly better than if they had received gesture plus speech sequentially or if they had heard only speech. Simultaneous gesture and speech had other important effects—generalization and retention. Children who received simultaneous gesture plus speech generalized what they had learned to problems in a new format (e.g., $\_\_ + 7 = 3 + 5 + 7$, or $3 + 5 + 7 = \_\_ + 4$), and retained what they had learned a month later, better than children who received sequential gesture plus speech or sequential speech plus speech. Seeing gesture, particularly when it is produced simultaneously with speech, is an effective teaching tool so effective that it helps learners transfer and remember the knowledge gained.

Hostetter (2011) conducted a meta-analysis of the impact gesture has on communication. She found a moderate (and beneficial) effect of gesture, which was moderated by three factors: (a) topic—gestures depicting motor actions are more communicative that gestures depicting abstract ideas, (b) match between gesture and speech—gesture has a bigger effect on communication when they add information to the speech they accompany, and (c) age—children benefit more from gesture than adults do.

### *3.2.2. Doing our own gesture*

Cook and Tanenhaus (2009) discovered that listeners were influenced by the gestures they saw others produce when they described how they solved the TOH puzzle. When the listeners later solved the TOH puzzle on a computer, they mirrored the movements the speakers made in their gestures. Beilock and Goldin-Meadow (2010) asked whether the gestures that speakers *themselves* produce affect how they solve the TOH problem. They asked adults to solve the TOH puzzle using real disks. The disks not only differed in size but also in weight—the biggest disk had to be lifted with two hands; the smallest disk could be lifted with one or two hands. After the adults solved the TOH problem, they were asked to explain how they solved the puzzle. And they all gestured. The speakers sometimes produced a one-handed gesture to describe what they did with the littlest disk and sometimes they produced a two-handed

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gesture. The adults then solved the puzzle again—half used the same set of disks, and half used a set in which the littlest disk could no longer be lifted with one hand but needed two hands to be lifted. The more times the adults used a one-handed gesture during their explanations, the worse they did on the second round (more moves, more time)—but *only* when the disks were switched. Adults' own one-handed gestures had lulled them into expecting the disk to still be little in the second round. Importantly, if adults were not asked to give explanations between the two puzzle-solvings (and therefore did not produce gestures), there were no differences between the groups (Beilock & Goldin-Meadow, 2010; Goldin-Meadow & Beilock, 2010), underscoring the importance of actually gesturing. The gestures the speaker produced after round one had influenced how they went on to solve the puzzle in round two.

In the TOH study, speakers produced their own spontaneous gestures. A more convincing way of demonstrating whether one's own gestures influence thinking is to manipulate gesture. Goldin-Meadow, Cook, and Mitchell (2009) told children what to say and how to move their hands during a mathematical equivalence lesson. All of the 9- to 10-year-old children were taught to say the *equivalence* strategy in speech, which they produced before and after they solved each problem during the lesson. One group received no other instruction. A second group was told to put a V hand under the 3 and 5 in the problem $3 + 5 + 7 = \_\_ + 7$, and then point at the blank, a *correct grouping* strategy, which indicates the two numbers that should be grouped and their sum put in the blank). A third group was taught to point at the 5 and the 7 on the left side of the equation and then point at the blank, a *partially correct* grouping strategy, which shows that two numbers can be grouped but indicates the wrong two numbers. Children who produced the correct grouping strategy in gesture performed significantly better on the posttest after the lesson than children in the other two groups (Goldin-Meadow et al., 2009). The teachers did not produce the grouping strategy in either gesture or speech, and the children produced it only in their gestures. Many of the children in this group did, however, produce the grouping strategy in their speech *after* the lesson; and producing grouping in speech on the posttest after the lesson mediated the effect the *correct grouping strategy* had on posttest success. The way children move their hands during a lesson can influence how they learn (Goldin-Meadow et al., 2009) and also how much they retain (Cook, Mitchell, & Goldin-Meadow, 2008)

In sum, our minds can change when we see others gesture *and* when we ourselves gesture. However, when pitted against each other, doing our own gesture is a more powerful learning tool than seeing someone else's gesture, at least when young children learn about mental rotation (Goldin-Meadow, Levine, et al., 2012).

### *3.3. Gesture serves many functions: The perfect storm is in our hands*

We do not really know why gesture changes our minds. But we have many good leads and evidence for, and evidence against, some of them. One hypothesis is that using two modalities—the manual and the oral—facilitates learning. Another is that using two representational formats—the discrete categorical format found in language and the continuous imagistic format found in gesture—is what facilitates learning. We cannot test these two hypotheses in speakers because gesture and language are always produced in two differ-

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ent modalities. But we can test the hypotheses in signers whose gestures and language are produced in the same (manual) modality. If two modalities are key to gesture's role in learning, then signers should not experience the same effects that speakers do. But if two different representational formats are key, signers should not only produce gesture–*sign* mismatches (akin to gesture–speech mismatches), but those mismatches should predict future learning. Goldin-Meadow, Shield, et al. (2012) gave 9- to 10-year-old ASL signers mathematical equivalence problems to solve and explain, and then gave them a lesson on how to solve the problems, all conducted in ASL. Only children who could not solve the problems were included in the study. We found that children did produce gesture–sign mismatches, and the more mismatches a child produced before the lesson, the better the child did after the lesson. Gesture gets its power not from the juxtaposition of two modalities but rather from the juxtaposition of two representational formats. The studies of gesture produced simultaneously versus sequentially with speech (Congdon et al., 2017) suggest that having these two different representational formats produced at the same time improves learning, at least when they are *seen by learners* (see Carrazza, Wakefield, Hemani-Lopez, Plath, & Goldin-Meadow, 2021, for evidence that simultaneity may be less important when gesture is *produced by learners*).

The juxtaposition of the oral and manual modalities may not be what gives gesture its power in predicting learning, but this fact does not rule out the potential importance of the manual modality. Gesture could be a powerful tool because it brings the body into learning. Indeed, children who learn a task through gesture activate the same motor areas in the brain as children who learn through action (James & Atwood, 2009) when later asked to solve the task in a scanner (Wakefield, Congdon, Novack, Goldin-Meadow, & James, 2019). The fact that gestures behave like action in many respects has led to a new framework, Gesture as Simulated Action (GSA; Hostetter & Alibali, 2008), for explaining the mechanism underlying gesture production. When we say the word "throw," we simulate a throwing movement. We do not necessarily produce the movement, but activity in our brains indicates that throwing is on our minds—the same brain areas that are activated when we throw are activated when we talk about throwing (Pulvermüller, 2005). The idea that we simulate actions when we think and speak is known as *embodied cognition* (Shapiro, 2014; Wilson, 2002; Wilson & Knoblich, 2005). This idea forms the basis for GSA, which hypothesizes that action simulations lead to gesture. When a certain threshold of brain activation is reached (people may have different thresholds), throwing becomes visible in a gestural simulation of the act.

Although involving the body in learning may heighten learning, the body cannot be the whole story for gesture simply because gesture (e.g., gesturing twisting a jar lid) affects learning differently from actions that have a direct impact on the world (e.g., twisting the jar lid open)—but both are performed by the body. Novack, Congdon, Hemani-Lopez, and Goldin-Meadow (2014) found that getting children to produce actions instantiating the *grouping* strategy on mathematical equivalence problems (i.e., moving the numbers in a pattern that instantiated the strategy) was just as effective in teaching them how to solve problems on which they had been taught as getting them to produce gestures instantiating the strategy. But gesturing was *more* effective than acting on the numbers in getting the children to generalize what they had learned during the lesson. Wakefield, Hall, James, and Goldin-Meadow (2018) found the same effect in toddlers learning made-up words for actions and also found that

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gesture promoted retention better than actions (see also Levine, Goldin-Meadow, Carlson, & Hemani-Lopez, 2018).

Gesture might also affect learning by grabbing learners' attention, helping them follow a teacher's speech. Wakefield, Novack, Congdon, Franconeri, and Goldin-Meadow (2018) found some support for this hypothesis. Children who saw the teacher gesture were indeed more likely to follow the teacher's words than children who saw no gesture and were more likely to solve the problems correctly after the instruction. Gesture guided the children's attention and that guided attention was associated with later success. However, Wakefield, Novack et al. (2018) also found that gesture in instruction did more than direct attention to speech. Children who saw gesture and followed the teacher's words were more likely to succeed on the problems than children in the no-gesture condition who managed to follow the teacher's words on their own without teacher gesture. A priori we might have guessed that following the teacher's words without help from gesture would be a better predictor of success than following the teacher's words because their attention was guided by gesture. But we would be wrong. Seeing the teacher's gestures seemed to be helping learners extract information relevant to solving the problem from the teacher's speech—without those gestures, children were less likely to learn even if they did follow the teacher's words.

Finally, gesture might be helpful because it puts thoughts out into space, which makes it easier to work with those thoughts. Clark and Chalmers (1998; see also Clark, 2008) argue that the mind extends beyond the body to include the tools, symbols, and other artifacts we use when we engage the world. Gesture, which represents ideas and puts those representations out there for all the world to see, could be a body-bound tool that effects change by extending the mind.

Laying ideas out in space, even ideas that are not inherently spatial, can pave the way for using cognitive operations that rely on space (Newcombe, 2017). Take, for example, the *Method of Loci*, a strategy for recalling lists of items (O'Keefe & Nadel, 1978). You imagine yourself placing the items that you want to remember in different locations around a room (e.g., on the couch, on the table, near the lamp, etc.) and then recall each of the items by revisiting in your mind the locations you have used and calling up the image of the item in that location (i.e., the item on the couch, the item on the buffet, the item near the lamp, etc.). Perhaps gesture could be used in comparable ways. By gesturing about different ideas in space, you are grounding them in those spaces and can perhaps use the spaces to recall them. This is a good area for future research.

Gesturing thus has many functions. However, gesture may be a powerful learning tool because it does all of these things (and more) *in the same event*. Gesture is the perfect storm in the sense that it helps you focus your thoughts, remember the information you gestured, lightens your cognitive load, externalize your thoughts by bringing the body into thinking, bring a second modality and a second representational format into thinking, promote abstraction, and fill in gaps left by language. Although the term is typically used to describe a destructive phenomenon, I use it here to describe a *powerful* confluence of factors within a single act that drastically alters an event, in this case, a learning event.

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## 4. Conclusion: Why we should care about hands

Gesture is a naturally used and accessible behavior that can help researchers discover the uncharted parts of the mind. When the hands take on the primary burden of communication in homesign, they reveal fundamental properties of thought that shape language. When the hands are used in concert with an established language, they can reveal ideas that go beyond that language, inserting them into the conversation and thus influencing that conversation. Knowing about the mind that is hidden in our hands can enrich and extend our understanding of how we think and learn.

But gestures can also be put to practical use—not only by teachers (Goldin-Meadow & Singer, 2003) but also by parents (Goldin-Meadow et al., 2007), clinicians (Goldin-Meadow, 2020b; Sauer, Levine, & Goldin-Meadow, 2010), lawyers (Broaders & Goldin-Meadow, 2010), and really anyone who interacts face-to-face with others (see Goldin-Meadow, 2023). Importantly, gesture has the potential to level the playing field in education—adding gesture to a lesson can boost performance in children from less advantaged homes so that it is equal to performance in children from advantaged homes (Tank et al., 2019), a very exciting and promising application of the power of gesture in bridging longstanding divides. One step toward this leveled playing field is to make sure that teachers, and their hands, are visible, particularly in the online lessons students see.

The gestures we all produce with our hands complete our thoughts, which means that an encompassing picture of human communication contains both language and gesture. In order to fully understand ourselves and each other—how we develop, how we teach, how we know each other, even how we know what we ourselves know—we have to reconceptualize communication as a dynamic between language and gesture.

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