Language, Cognition and Neuroscience, 2015
Vol. 30, No. 8, 899–911, http://dx.doi.org/10.1080/23273798.2015.1016978

TARGET ARTICLE

Studying the mechanisms of language learning by varying the learning environment and the learner

Susan Goldin-Meadow*

Department of Psychology, University of Chicago, 5848 South University Avenue, Chicago, IL 60637, USA

(*Received 29 August 2014; accepted 23 January 2015*)

Language learning is a resilient process, and many linguistic properties can be developed under a wide range of learning environments and learners. The first goal of this review is to describe properties of language that can be developed without exposure to a language model – the resilient properties of language – and to explore conditions under which more fragile properties emerge. But even if a linguistic property is resilient, the developmental course that the property follows is likely to vary as a function of learning environment and learner, that is, there are likely to be individual differences in the learning trajectories children follow. The second goal is to consider how the resilient properties are brought to bear on language learning when a child is exposed to a language model. The review ends by considering the implications of both sets of findings for mechanisms, focusing on the role that the body and linguistic input play in language learning.

Keywords: gesture; homesign; innate; socioeconomic status; unilateral brain injury

Although time-consuming, it is possible to describe the behaviours that children produce as they acquire language – that is, what children do when they learn language. The harder task is to figure out *how* they do it. This is the question that organises this review.

Many theories have been offered to explain how children learn language. Although there is disagreement in the details, all modern-day accounts accept the fact that children come to language learning prepared to learn. The central disagreement lies in what each theory takes the child to be prepared with – a general outline of what language is? a set of processes that lead uniquely to the acquisition of language? a set of processes that lead to the acquisition of any skill, including language?

The premise of a nativist account of language learning is that children learn a linguistic system governed by subtle and abstract principles without explicit instruction, and even without enough information from the input to support induction of these particular principles (as opposed to other principles) – "Plato's problem" or the poverty of the stimulus argument (Chomsky, 1999). If there is not enough information in the input to explain how children learn language, the process must be supported by innate syntactic knowledge and language-specific learning procedures (e.g., Pinker, 1984, 1989).

The nativist position entails two claims: (1) At least some of the principles of organisation underlying language are language-specific and not found in other cognitive systems; and (2) The procedures that guide the implementation of these principles are themselves innate. Although these two claims are linked in many theoretical accounts, they need not go hand-in-hand. The principles underlying linguistic knowledge might be specific to language and, at the same time, implemented through general, all-purpose learning mechanisms. This view constitutes the position that is often known as a social or cognitive account of language learning. Social and cognitive accounts claim that there is, in fact, enough information in the linguistic input children hear, particularly in the context of the supportive social environments in which they live, to induce a grammatical system with few, if any, assumptions about the structure of the to-be-learned system.

But what if a child were able to develop the same grammatical system when not exposed to any language model at all? These properties of language would then be considered *resilient* in the sense that they do not require a language model to be developed. The properties would also be good candidates for innate structures that guide language learning, although it is important to note that the structures could be either specific to language or applicable to other cognitive tasks as well. In the first part of this review, I describe an empirical programme of research designed to discover what children are prepared with when they come to language learning – the resilient properties of language.

Although (as we will see) children come to language learning with innate ideas about how to structure their language, predispositions can only take them so far – they need to learn the language of their community and, to do

*Email: sgm@uchicago.edu

so, they must make use of the linguistic environment that surrounds them. We know that environmental factors can play an important role even in traits whose development is largely governed by innate factors; for example, the average height of the Japanese population increased after the Second World War as a function of marked improvements in nutrition (Takahashi, 1966). And language is no exception – toddlers from low socio-economic status (SES) families in the USA tend to have smaller vocabularies than toddlers from high SES families (Hart & Risley, 1995; Hoff, 2006), a gap that widens until age 4 and then remains relatively constant throughout the school years (Farkas & Beron, 2004). Variations in the learning environment to which a child is exposed can thus affect the pacing at which language is learned, as can variations in the learner.

In the second part of this review, I examine the impact that variations in learning environments (homes that vary substantially in SES) and variations in learners (children with and without pre- or perinatal brain injury) have on language learning. I focus on two behaviours known to vary across environments and individuals – parent speech and child gesture – behaviours that have the potential to play a role in creating differences across children in linguistic skills. I end by considering the implications of both parts of the review for mechanisms of language learning.

1. Removing linguistic input from the learning environment: resilient properties of language

1.1. Identifying resilient properties of language

Degrading the linguistic input to which a child is exposed and then exploring the effects that the manipulation has on language learning would be the best way to examine the skills children themselves bring to learning. We cannot, of course, intentionally degrade children's linguistic input. There are, however, children who find themselves without access to usable linguistic input – deaf children with hearing losses so extensive that they cannot naturally acquire oral language, and born to hearing parents who have not exposed them to a conventional sign language. Under such inopportune circumstances, these deaf children might be expected to fail to communicate altogether. This turns out not to be the case. Despite their degraded language-learning conditions, these children develop gestural communication systems, called *homesigns*, that contain many of the properties of natural language (Goldin-Meadow, 2003a).

It is important to note here that deaf children who are exposed to a conventional sign language by their deaf parents acquire that language as naturally, and on roughly the same timetable, as hearing children acquire spoken language from their hearing parents (Lillo-Martin, 1999; Newport & Meier, 1985). There is thus no reason to believe that a homesigner has different language-processing skills than any other child – the difference is that homesigners apply those skills to, at best, limited data. The question is – how far can a child's information processing skills take him or her when applied to non-linguistic data?

Homesign has been studied in individuals in the USA (Goldin-Meadow & Mylander, 1984), Taiwan (Goldin-Meadow & Mylander, 1998), Turkey (Goldin-Meadow, Namboodiripad, Mylander, Özyürek, & Sancar, 2015), Brazil (Fusellier-Souza, 2006) and Nicaragua (Coppola & Newport, 2005). The gestures that homesigners produce are, for the most part, transparent representations of objects, actions and attributes. For example, they point at entities in the surrounding context to refer to those entities, and they even point at empty spaces to refer to entities that are not present in the context (Butcher, Mylander, & Goldin-Meadow, 1991; Morford & Goldin-Meadow, 1997). Homesigners also create iconic gestures that represent objects and actions by capturing features of the referent (e.g., making a circle out of the thumb and index finger to represent a penny, *penny*; rotating fists in front of the body to represent pedalling a bicycle, *pedal*).

Homesigners introduce a syntactic structure into their communications despite the fact that the transparency of their gestures makes it relatively easy to understand those gestures even without any structure. For example, homesigners string gestures together following a consistent order (Feldman, Goldin-Meadow, & Gleitman, 1978; Goldin-Meadow & Feldman, 1977) – gestures representing entities playing the patient role (e.g., a grape) precede gestures representing the action (e.g., eat) even though it is clear from context alone that the grape is to be eaten and not the other way around. In other words, homesign contains structure that a communication partner does not seem to need, suggesting that the structure is not for the partner but instead reflects how homesigners organise their thoughts for communication.

As another example, the homesigner's gestures are composed of parts, akin to a morphological system (Goldin-Meadow, Mylander, & Butcher, 1995; Goldin-Meadow, Mylander, & Franklin, 2007). For example, the "O" handshape representing a round object is combined with an "arc" motion representing a put-down action to create the gesture "put-down round object". The "O" handshape can also be combined with other motions to refer to other actions involving round objects, and the "arc" motion can be combined with other handshapes to refer to other objects that can be moved in this way. The product is a set of gestures, each of which is a transparent reflection of its referent. Here again, the gestures' transparency makes them easy to interpret, particularly in context, rendering the combinatorial system unnecessary from the communication partner's point of view. But the combinatorial system does provide a mechanism for creating new gestures, which could be useful for the homesigner.

The gesture sentences homesigners produce can be characterised by simple syntactic structures. First and foremost, their sentences contain gestures serving a nominal role, which are treated differently from gestures serving a predicate role (Goldin-Meadow, Brentari, Coppola, Horton, & Senghas, 2015). As in many conventional sign languages (Benedicto & Brentari, 2004), the nominal gesture in a sentence does not vary with grammatical context – the handshape used for the nominal in an agent context (*book* in *Someone put the book down*) is the same as the handshape used for the same nominal in a no-agent context (*book* in *The book fell down*). In contrast, the predicate gesture does vary as a function of grammatical context, and the variation is systematic – *handling* handshapes are used for the predicate in an agent context (*put down*), *object* handshapes are used for the predicate in a no-agent context (*fell down*); in other words, there is morphological variation as a function of agency. Homesigners have thus introduced a distinction central to all natural languages into their gesture systems.

Second, homesign has a hierarchical structure. More than one gesture can function as a nominal, creating a complex nominal constituent that is embedded within a larger sentence. For example, a point gesture at a penny (*that*) can be combined with an iconic gesture for the penny (*penny*), both of which are then combined with a predicate (*give*): [[*penny–that*]–*give*], produced to request that the penny be given to the child. The *penny-that* combination represents an argument serving the patient role and, as such, precedes the gesture for the act, *give*. Interestingly, sentences containing nominal constituents are longer than would be expected by chance simply because the *penny-that* combination functions as a chunk and thus seems to reduce psychological demand on sentence length (Hunsicker & Goldin-Meadow, 2012). As another example of hierarchical structure, gestures for one proposition can be combined with gestures for a second proposition, creating a complex sentence (Goldin-Meadow, 1982); e.g., a gesture for *climb*, followed by a gesture for *sleep*, followed by a point at a horse, is used to comment on the fact that the horse climbed the house (proposition 1) and now sleeps (proposition 2).

Third, homesign contains lexical markers that modulate the meanings of sentences, negation and questions (Franklin, Giannakidou, & Goldin-Meadow, 2011). The negative marker (side-to-side headshake) is positioned at the beginning of sentences, and the question marker (a palm-oriented face down flipped to palm up) is positioned at the ends of sentences. The ends of sentences are also marked prosodically (Applebaum, Coppola, & Goldin-Meadow, 2014).

Finally, homesign is a natural language in terms of its functions, assuming the typical roles that conventional languages serve, signed or spoken (Goldin-Meadow, 2003a). Homesigns are used to make requests of others; to comment on the present and non-present; to make generic statements about classes of objects; to tell stories about real and imagined events; to talk to oneself; and to talk about language.

Importantly, the structures found in a homesigner's gestures cannot be traced back to the gestures that the child's hearing parents produce when they talk. For example, the hearing mother of the homesigner who used nominal constituents in his gestures never combined a pointing gesture at an object with an iconic gesture for the same object (Hunsicker & Goldin-Meadow, 2012). As another example, hearing parents first produce complex sentences in their co-speech gestures after their children first produce them, and produce them less often than their children (Goldin-Meadow & Mylander, 1998). The properties of language that appear in homesign are thus not only developed without input from a conventional language model, but are also not found in the co-speech gestures in the surrounding hearing community. In this sense, they are resilient and reflect biases humans bring to language learning.

1.2. Are the biases responsible for the resilient properties of language specific to language?

Although it is possible that the biases homesigners bring to communication are specific to language, it is equally likely, a priori, that these biases are recruited from a repertoire of cognitive processes that can be applied to any domain, for example, the ability to sequentialise, chunk, embed, etc. An intriguing question is why the deaf children recruit the particular set of cognitive processes that they do, and not others, into their homesign systems.

For example, the handshapes around which homesigners build their morphological systems represent the size and shape of objects (Goldin-Meadow et al., 1995, 2007). But the hand can be used to represent many types of object properties. For example, Lederman and Klatzky (1987, 1990) have isolated a variety of distinctive hand motions that people use to explore different object properties – repetitive shearing motions along a surface can be used to explore the texture of an object; applying pressure to the surface of an object can be used to explore the hardness of an object; resting the hand on an object can be used to explore the temperature of an object; and unsupported lifting can be used to explore the weight of an object. Homesigners could have recruited exploratory movements of this sort (i.e., movements that highlight the substance or material out of which an object is constructed) as the basis for their object categories, but they do not.

Instead, homesigners base their object categories on exploratory movements that extract information about the size and shape of objects. Importantly, the size and shape properties that homesigners grammaticise in their morphological systems (Goldin-Meadow et al., 1995, 2007) are routinely grammaticised in both spoken (Allan, 1997) and signed (Schembri, 2003) languages – unlike properties like texture, hardness, temperature and weight, which have not been found to be grammaticised in any language described thus far. Thus, although many of the morphemes found in homesign are likely to have been derived from haptic knowledge of objects (cf. Klatzky, McCloskey, Doherty, Pellegrino, & Smith, 1987), homesigners are selective about which aspects of their haptic knowledge they draw upon as a basis for their morphological systems – and that selectivity leads to a morphological system that closely resembles systems found in natural languages, signed and spoken.

In other words, some general cognitive skills (in this case, the ability to represent size and shape, rather than weight, texture, temperature) may play a special role in human language (see Talmy, 1988, and Cinque, 2013, for similar discussion of notions that are preferentially incorporated into grammatical systems). The larger point is that homesigners have some cognitive skills that they do *not* recruit for their gesture systems and others that they do. The question we need to address in future work is – what determines which properties do and do not find their way into homesign? More generally, what determines the biases children bring to language learning? The answer cannot be linguistic input.

1.3. Studying conditions that foster fragile properties of language

Homesigners are not likely to be able to develop all of the properties found in natural language. The properties that homesigners do not develop are properties whose development is sensitive to learning conditions that vary from the typical and, in this sense, are relatively fragile. It is difficult to point with certainty to properties not found in homesign, as their absence could reflect the experimenter's inability to find these properties, rather than the homesigner's inability to create them. It would be a methodologically stronger finding if we could demonstrate that a property hypothesised to be absent from homesign can be found, using the same tools, in another manual system. A new sign language emerging in Nicaragua not only gives us this methodological lever, but also allows us to explore particular conditions that foster the development of the fragile properties of language.

Nicaraguan Sign Language (NSL) was born in the late 1970s and early 1980s when rapidly expanding programmes in special education brought together in great numbers deaf children and adolescents who in all likelihood were, at the time, homesigners (Senghas, 1995). NSL has continued to develop as new waves of deaf children enter the community and learn to sign from older peers, and offers us the opportunity to explore three types of conditions that could have an impact on the structure of language.

First, we can explore the effect that increasing age has on the complexity of homesign. Some Nicaraguan homesigners do not come into contact with deaf signers even as adults and, as a result, continue to use their homesign systems with the hearing individuals in their worlds into adulthood. Analyses of adult homesign in Nicaragua have uncovered linguistic structures that have thus far not been identified in child homesign – the grammatical category of subject (Coppola & Newport, 2005); points at space used to identify non-present referents and play a grammatical role in sentences (Coppola & Senghas, 2010); systematic differences in finger complexity in *object* vs. *handling* handshapes (Brentari, Coppola, Mazzoni, & Goldin-Meadow, 2012). Future work is needed to determine whether these properties can be developed by child homesigners.

Second, we can explore the effect that sharing a communication system within a group has on the complexity of language. Before coming together, the first cohort of NSL interacted only with hearing individuals who did not share their homesign systems (e.g., Coppola, Spaepen, & Goldin-Meadow, 2013). Having a group with whom they could communicate meant that the first cohort of signers were not only producers of their linguistic system but also receivers of the system, a circumstance that could lead to a system with greater systematicity – but perhaps less complexity, as the group may need to adjust to the lowest common denominator.

Third, we can explore the effect that transmitting a communication system to a new generation has on complexity. The second cohort of NSL had the first cohort as their linguistic input. Having a system with an established lexicon and structural regularities to serve as a base allowed the second (and subsequent) cohorts to further develop their communication system (e.g., Senghas, 2003). Once learners are exposed to a system that has linguistic structure (i.e., cohort 2 and beyond), the processes of language change may be similar to the processes studied in historical linguistics. One interesting question is whether the changes seen in NSL in its earliest stages are of the same type and magnitude as the changes that occur in mature languages over historical time.

Studies of differences across these Nicaraguan groups are in the early stages. However, there is preliminary evidence that plural marking differs in systematic ways across the groups. Homesigners, both adult (Coppola et al., 2013) and child (Abner, Namboodiripad, Spaepen, & Goldin-Meadow, 2015), modulate their gestures to indicate multiple objects or events, that is, they use a plural marker. They use this marker in no-agent contexts (e.g., they use it to indicate that many pens are on the table) but not in agent contexts (e.g., they do not use the marker to indicate that many pens are put down on the table; Horton, Goldin-Meadow, & Brentari, 2014). In contrast, members of the NSL cohort 2 use the plural marker in both no-agent and agent contexts, suggesting that the distinction is fully grammaticised in this cohort.

An interesting twist to this result is that members of NSL cohort 1 behave like homesigners, not like cohort 2, with respect to the plural marker (Horton et al., 2014). In other words, having a community of signers does not lead to grammaticisation of this structure – it becomes fully grammatical only when passed through a fresh generation of learners. Having a community of signers (as in cohort 1) does appear to be essential for the development of some properties of language, although thus far the properties appear to be lexical rather than grammatical (Goldin-Meadow et al., 2015). Future work in Nicaragua will allow us to determine whether having a linguistic community is necessary for the emergence of any grammatical properties at all.

Overall, the unique situation in Nicaragua allows us to determine which properties of language are not developed by homesigners and, in this sense, are not resilient, and to explore conditions that have the potential to support the appearance of these more fragile properties in communication.

2. Varying the learning environment (SES) and the learner (brain injury): pacing language learning

Most children acquire language with relative ease and, within broad outlines, acquire language according to a common trajectory. However, within the striking commonalities that characterise language learning in children, there are equally striking individual differences in the rate and timing of lexical and syntactic growth (e.g., Fenson et al., 1994; Hart & Risley, 1995; Huttenlocher, Haight, Bryk, Selzer, & Lyons, 1991; Miller & Chapman, 1981). Understanding the source of these individual differences has the potential to provide insight into how children bring the resilient properties to bear on language learning in order acquire the particular language to which they are exposed.

One strategy for exploring individual differences in language learning is to select conditions likely to maximise those differences, and then observe the impact on language learning. Maximising individual differences can be accomplished in (at least) two ways. We can observe children who come from homes that vary in SES and thus are likely to receive differing amounts and types of linguistic input, an *external* resource for language learning. We can also observe children who have experienced pre- or perinatal unilateral brain injury; in addition to receiving varied linguistic inputs, these children bring varying *internal* resources to the task of language learning. We can thus explore the joint effects that environmental variation (variations in linguistic input) and internal variation (variations in lesion characteristics) have on language learning. I focus here on two behaviours: parent speech, which has been found to play a role in creating differences in linguistic skills across children, and child gesture, which has been found to index differences in linguistic skills across children (and perhaps even create them).

2.1. The relation between parent speech and child language

2.1.1. Variation in parent speech and SES

Parents in low SES homes spend, on average, less time engaged in mutual activities with their children (e.g., Heath, 1983; Hess & Shipman, 1965) and, perhaps as a result, talk less to their children (Hoff-Ginsberg, 1990), than do parents in higher SES homes, resulting in differences in the vocabulary (Hart & Risley, 1995) and syntax (Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002) that children hear. This variation in parent speech, in turn, has an impact on child language, both vocabulary and syntax.

For example, Huttenlocher, Waterfall, Vasilyeva, Vevea, and Hedges (2010) analysed videotapes of 47 families selected to reflect the economic and ethnic diversity of Chicago and thus came from homes that varied widely in SES (see Goldin-Meadow et al., 2014, for an overview of the sample and study). Rather than focus on total amount of parent and child speech, Huttenlocher and colleagues analysed diversity – the variety of words, phrases and clauses produced by parents and children. They addressed the important question of "who is influencing whom" by using lagged correlations (e.g., using parent speech at 26 months to predict child speech at 30 months, parent speech at 30 months to predict child speech at 34 months, and so on). Lagged correlations between parent speech at an earlier session and child speech at a later session (forward correlations) and between child speech at an earlier session and parent speech at a later session (backward correlations) allow a relatively fine-tuned assessment of directionality.

For vocabulary, forward and backward correlations were both significant and equally large; that is, earlier parent speech predicted later child speech, and earlier child speech predicted later parent speech, suggesting a reciprocal relation between parent and child for vocabulary. In contrast, for syntax, forward correlations were significant but backward correlations (early child predicting later parent syntax) were not, suggesting an unequal relation between parent and child for syntax. The different patterns for vocabulary and syntax suggest that particular parent behaviours, rather than overall parent intelligence, underlie the correlations with child language learning, and that parent input may play a different kind of role in syntax-learning than in vocabulary-learning.

Huttenlocher and colleagues (2010) also explored whether SES differences in child language were mediated by differences in parent speech. They first analysed SES effects without parent speech, and then later included parent speech in the analyses. SES effects turned out to be smaller when parent speech was included in the models predicting child vocabulary and syntax, suggesting that the relation between SES and these aspects of child language is partially mediated by parent speech.

The diversity measures used by Huttenlocher and colleagues (2010) depend in part on how much parents talk to their children, that is, on the quantity of their speech. Cartmill and colleagues (2013) used a paradigm developed by Gillette, Gleitman, Gleitman, and Lederer (1999) to develop a measure of quality of parent input that was independent of quantity. They determined how easy it was to guess from non-linguistic context alone a randomly selected set of nouns produced by 50 of the parents in the Chicago sample. The more easily a word can be guessed, the more likely a child is to figure out, and then learn, the word – easily guessed words thus reflect high-quality word-learning experiences.

Cartmill and colleagues (2013) found that parents varied in the quality of word-learning experiences they gave their children at 14 and 18 months, and that this variability predicted children's comprehension vocabulary three years later, controlling for quantity of parent input. Quantity and quality did not correlate with each other, and each accounted for different aspects of variance in child outcome. In other words, how much parents talk to their children (quantity), and how parents use words in relation to the non-linguistic environment (quality), provide different kinds of input into early word learning. Quantity of parent input to word learning was positively related to SES (as has been found by many others). But, interestingly, quality of parent input did *not* vary systematically with SES, suggesting that the quality of word-learning experiences parents offer their children is an individual matter, unrelated to economic resources in the home.

2.1.2. Variation in parent speech and child brain injury

Another potential source of individual differences in language learning is the intactness of the learner's brain. As a group, children with unilateral brain injury to either hemisphere tend to acquire the early appearing aspects of language on time or with minimal delays (e.g., Marchman, Miller, & Bates, 1991). But they experience iterative difficulty with each aspect of language development as the skill comes online (Stiles, Reilly, Levine, Trauner, & Nass, 2012), including complex syntactic (Levine, Huttenlocher, Banich, & Duda, 1987) and narrative (e.g., Demir, Levine, & Goldin-Meadow, 2010) skills. There is, however, considerable variability across children with unilateral brain injury; that is, there are individual differences in the language skills of children with brain injury, differences that could be related to variation in parent speech and to variation in the extent of the injury.

Many studies have explored the relation between differences in language skill and biological characteristics (lesion laterality, location and size) in children with brain injury (e.g., Feldman, 2005), but few have looked at these differences in relation to parent speech. Doing so has resulted in interesting findings. For example, Rowe, Levine, Fisher, and Goldin-Meadow (2009) analysed vocabulary growth (word types) and syntactic growth (Mean Length of Utterance, MLU) in children with brain injury, comparing these children to the children without brain injury in the Chicago sample.

Corroborating previous research, their first finding was that language development is a relatively resilient process even in the face of early brain injury. Between 14 and 46 months, children with brain injury lagged slightly behind children without brain injury in vocabulary production, but there was wide and overlapping variation within and across groups. Differences across groups in syntax (MLU) were more pronounced, particularly after three years of age, adding support to previous findings that deficits often emerge only on more difficult linguistic tasks (e.g., producing complex syntactic forms; MacWhinney, Feldman, Sacco, & Vaaldes-Perez, 2000; Weckerly, Wulfeck, & Reilly, 2004). Language development after pre- or perinatal brain injury thus may appear more resilient when earlier developed, less complex, aspects of language development are considered.

Turning next to the relation between parent speech and child language, Rowe and colleagues (2009) found, not surprisingly, that children with less input at 14 months had lower vocabularies at 30 months than children with more input, and that acceleration in growth was more profound for children with high than low input. The relation between parent speech and vocabulary did not differ based on brain injury status.

However, syntax showed a different pattern – there was an interaction between parent speech and brain injury status for MLU, but not for word types. In particular, there was a bigger difference between rates of growth in MLU for high- and low-input children with brain injury than for high- and low-input children without brain injury. Parent speech thus appears to act similarly as a predictor of growth in vocabulary for children with and without brain injury, but to be a more potent predictor of growth in syntax for children with brain injury than for children without brain injury. The effect that parent speech has on children with brain injury, compared to children without injury, can differ as a function of linguistic property.

Rowe and colleagues (2009) also examined lesion size, lesion type (periventricular, ischemic) and seizure history in the children with brain injury, and found that these characteristics contributed to language trajectories as well.

Plasticity after early lesions should therefore be thought of as a joint function of variability in the environment (parent speech) and variability in the organism (lesion characteristics and neurological manifestations).

2.2. The relation between child gesture and child language

Speakers in all cultures move their hands when they speak – they gesture. In fact, individuals who are blind from birth, and thus have never seen anyone gesture, move their hands when they speak, even when speaking to other blind individuals (Iverson & Goldin-Meadow, 1998). Gesture is thus a robust part of talking in proficient speakers, and is also a frequent behaviour in children learning to speak. In fact, children often use gesture before they begin to use words (Bates, 1976), and gesture continues to be part of a child's communicative repertoire after the onset of speech, serving to extend the child's communicative range (e.g., a child says "gimme" while pointing at a cracker; gesture makes it clear what the object of "gimme" is; see Greenfield & Smith, 1976). But there is variability in gesture use across children, and this variability is related to both external (SES) and internal (brain injury) factors.

2.2.1. Variation in child gesture and SES

Rowe and Goldin-Meadow (2009a) studied 50 children in the Chicago sample at 14 months and used number of gesture types (the number of different meanings conveyed using gesture, e.g., point at dog = *dog*, point at cup = *cup*) as a measure of early gesture use. They found that gesture use varied with SES – children from low SES homes used fewer gesture types than children from high SES homes, even controlling for child speech (word types, the number of different intelligible word roots). Importantly, there was no relation between SES and child word types at 14 months. Thus, at a time when we do *not* yet see differences as a function of SES in child speech, we do see them in child gesture. Children do not typically begin to gesture until around 10 months. SES differences are thus evident a mere four months (and possibly even sooner) after the onset of child gesture.

Moreover, the variability that we see in child gesture at 14 months was related to the size of the child's spoken vocabulary (as measured by the Peabody Picture Vocabulary Test, PPVT) at 54 months, more than three years later. In fact, the often-replicated relation between SES and child vocabulary at school entry (in this case, PPVT at 54 months) was partially mediated by child gesture at 14 months; that is, the fact that children from high SES homes had larger vocabularies at 54 months was partially explained by their greater use of gesture at 14 months. Finally, the relation between SES and child gesture at 14 months was mediated, at least in part, by parent gesture at 14 months; in other words, the fact that children from high SES homes gestured more at 14 months was partially explained by their parents' greater use of gesture at 14 months. Importantly, however, parent gesture at 14 months did *not* have a direct relation to child vocabulary at 54 months – it was related to child gesture at 14 months, which, in turn, was related to child vocabulary at 54 months.

In general, child gesture appears to be a reliable index of a variety of linguistic achievements. For example, the particular referents that a young child indicates in gesture predict which words will soon enter that child's spoken vocabulary (Iverson & Goldin-Meadow, 2005). As another example, children vary in the age at which they produce combinations in which speech conveys one idea and gesture another (e.g., *nap* + point at bird) and this variability predicts the age at which children produce their first two-word utterance (*bird nap*; Goldin-Meadow & Butcher, 2003; Iverson & Goldin-Meadow, 2005). Once two-word speech has begun, the types of gesture + speech combination children produce continue to predict the onset of different types of multi-word combinations (e.g., the onset of point + noun combinations, point at dog + *dog*, precedes, and predicts, the onset of determiner + noun combinations, *that dog*; Cartmill, Hunsicker, & Goldin-Meadow, 2014). Finally, children who use gesture (and not speech) to convey the viewpoint of characters in a story at age 5 are more likely to tell better-structured stories at ages 6, 7 and 8 than children who do not produce character-viewpoint gestures at age 5 (Demir, Levine, & Goldin-Meadow, 2014).

As should be obvious from these findings, using gesture early in development is not just an index of global communicative skill (i.e., a signal that the child is a good language learner or has a high level of intelligence). Rather, particular types and uses of early gestures are specifically related to particular aspects of later spoken language. Rowe and Goldin-Meadow (2009b) demonstrated this effect within a single group of children. In an analysis of 52 children in the Chicago sample, they found that, controlling for early spoken vocabulary, the number of different meanings children conveyed in gesture early in development predicted the size of their comprehension vocabularies several years later, whereas the number of gesture–speech combinations they produced early in development did not. In contrast, controlling for early spoken syntax, the number of gesture–speech combinations (e.g. point at hat + *dada* to refer to dad's hat) children produced early in development predicted the syntactic complexity of their spoken sentences several years later, whereas the number of different meanings conveyed in gesture early in development did not. Importantly, if the number of different meanings conveyed in gesture and the number of gesture–speech combinations are pitted against one another (along with a control for spoken vocabulary) in a single model, early gesture meanings significantly predict children's later comprehension vocabulary, but early gesture–speech combinations do not.

The selectivity with which children's gesture predicts the acquisition of different linguistic skills suggests that the gestures are reflecting not just general intelligence or overall language-learning ability, but rather skills specific to learning vocabulary or to learning syntax. These individual differences account for the pacing of learning, thus implicating the body as part of the causal mechanism underlying language learning (see Section 3.1).

2.2.2. *Variation in child gesture and child brain injury*

Children between 10 and 17 months of age with early right hemisphere lesions have been found to show delays in gesture (Bates et al., 1997; Marchman et al., 1991). Are children with brain injury who exhibit delays in gesture the same children who exhibit delays in vocabulary development? Delays in gesture might be expected to go hand-in-hand with language delays simply because gesture and language form an integrated system not only in adults (McNeill, 1992), but also in typically developing children at the early stages of language learning (Butcher & Goldin-Meadow, 2000; Goldin-Meadow, 2003b). If the gesture-language system is robust in the face of early unilateral brain injury, early gesture in children with brain injury should predict subsequent language development as it does in children without brain injury

Sauer, Levine, and Goldin-Meadow (2010) categorised 11 children with brain injury into two groups based on whether their gesture use at 18 months was within or outside of the range for 53 children without brain injury from the Chicago sample: five children with brain injury fell below the 25th percentile (low gesture) for gesture use in children without brain injury at 18 months; six fell above the 25th percentile (high gesture). Both groups of children with brain injury fell below the range for speech in children without brain injury at 18 months.

The interesting question is whether gesture at 18 months predicts later delays in speech. It does – children with brain injury classified as high gesturers at 18 months went on to develop production vocabularies (number of different words produced) at 22 and 26 months, and comprehension vocabularies (PPVT scores) at 30 months, that were within the range for children without brain injury, indeed close to the mean. In contrast, children with brain injury classified as low gesturers at 18 months remained below the range for children without brain injury at both 22 and 26 months in production, and at 30 months in comprehension. Early gesture can thus predict subsequent spoken vocabulary not only for children learning language at a typical pace, but also for those exhibiting delays.

The advantage of looking at early gesture (as opposed to speech) is that we can see differences between children who will eventually catch up and those who will not (at least not without intervention) *before* they display differences in speech – both groups of children with brain injury were below the norm in speech at 18 months. Early gesture can thus be used to diagnose risk for later language delays before those delays are evident in speech, and may even play a causal role in setting the stage for, and possibly ameliorating, the delays.

2.3. Pacing language learning and the resilient properties of language

We saw in Section 1 that children are prepared to learn a communication system characterised by a number of resilient properties of language – by simple syntactic structures (e.g., sentences containing elements that follow a consistent order, sentences containing words that are composed of parts, sentences containing elements that serve a nominal role, which are treated differently from elements that serve a predicate role); by hierarchical organisation (e.g., a complex nominal constituent embedded within a larger sentence, one proposition concatenated with another to form a complex sentence); by markers that modulate the meanings of sentences (e.g., negative and question markers); by functions that all conventional languages serve (e.g., making requests, commenting on the present and non-present, making generic statements, telling stories, talking to oneself, talking about talk). But children need to learn the particular instantiations of these properties that are displayed in the language to which they are exposed – which orders does the language follow? Which parts are the words decomposed into? Which features distinguish nominals from predicates? etc. Although all children seem to expect their communication systems to be characterised by the resilient properties of language, children vary in the rate at which they learn the particular instantiations of these resilient properties in the language they are learning.

These differences across individual learners might stem from inherent differences in the "strength" with which learners search for the resilient properties of language, a possibility that we have not explored here and that is difficult to test. But we have explored the impact that other internal factors, as well as external factors, have on individual differences in the pacing of language learning. We found that learners vary in the rate at which they acquire the words and sentence structures of their language as a function of the learning environments to which they are exposed (an external factor), and as a function of the gestures that they themselves produce (an internal factor). Interestingly, the rate at which children acquire some aspects of language does not appear to be affected by organic variations in the learner (e.g., the same models account for the impact of linguistic input on word learning in children with and without brain injury), whereas other properties are affected (e.g., linguistic input plays a bigger role in the acquisition of syntax in children with brain injury than in children without brain injury). To account for language learning, we need to know not only which linguistic properties children are searching for in their input, but also what that input looks like and what additional skills (e.g., gesture) and conditions (e.g., brain injury) children bring to the learning situation.

3. Implications for mechanisms of language learning

Language learning is a resilient process. The findings reviewed here underscore this resilience. Children raised in homes that vary widely in SES fall within the normative range for vocabulary and syntactic development, as do children with unilateral brain injury. Even more striking, deaf homesigners raised without access to usable linguistic input develop the rudimentary properties of natural language, suggesting that linguistic input is not essential for the development of at least some, resilient properties of language.

But even if a property of language is resilient, the developmental trajectory of that property may still be influenced by a variety of factors. Indeed, we find that the pacing of language learning – how quickly or slowly a particular property of language develops – is sensitive both to variations internal to the child (child gesture) and to variations external to the child (parent speech). I consider the implications of these findings for mechanisms of language learning in the next two sections.

3.1. Using the body to learn language

Children express ideas in gesture–speech combinations several months before they express the same ideas in speech alone. This fact makes it clear that children often have an understanding of a notion before they are able to express that notion in speech, thus eliminating one frequently held explanation for the slow acquisition of certain linguistic structures – the cognitive explanation, that is, that children do not express a given structure because they lack an understanding of the notion underlying the structure. Widening the lens with which we examine language learning to include gesture thus allows insight into when cognition does, and does not, shape the course of language learning.

Not only does the onset of gesture–speech combinations precede the onset of future linguistic milestones, but it also predicts their onset, opening the possibility that gesture plays a causal role in language learning, that it is part of the mechanism for language learning. Child gesture does, in fact, have the potential to influence language learning by eliciting timely speech from listeners.[1] A child's gestures can alert listeners (parents, teachers, clinicians) to the fact that the child is ready to learn a particular word or sentence. Listeners can then adjust their talk, providing just the right input to help the child learn the word or sentence (e.g., a child who does not yet know the word *bear* points at it and his mother responds, *yes, that's a bear*; or the child points at a bird while saying *nap* and his mother responds, *the bird is taking a nap.* Because they are finely tuned to a child's current state (cf. Vygotsky's, 1986, zone of proximal development), parent responses of this sort can be particularly effective in teaching children how an idea can be expressed in the language they are learning (see Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007).

Child gesture also has the potential to play a more direct role in language learning. Previous work on 9- to 10-year-old children has found that encouraging them to gesture when explaining how they solved a math problem makes them receptive to subsequent instruction on that problem (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007; see also Goldin-Meadow, Cook, & Mitchell, 2009). More relevant to language learning, in a seven-week intervention study conducted in children's homes, toddlers who were encouraged to gesture while looking at a book with the experimenter increased the rate at which they gestured when interacting with their parents, significantly more than toddlers who were not encouraged to gesture. Importantly, the toddlers who increased their rate of gesturing also increased the number of different words they produced, and did so more than children whose gestures did not increase (LeBarton, Raudenbush, & Goldin-Meadow, 2013). Gesturing can have an impact on word learning.

How does the act of gesturing pave the way for future linguistic constructions? One possibility is that gesturing gives children an opportunity to practice producing particular meanings by hand at a time when those meanings are difficult to produce by mouth (Iverson & Goldin-Meadow, 2005).

The fact that gesturing engages the body may also be important in making it a successful learning tool, in line with work arguing that much of cognition is embodied (e.g., Barsalou, 1999; Glenberg & Kaschak, 2002; Wilson, 2002). For example, James and Swain (2011) compared children who learned a novel word for an action performed on an object by either acting on that object or seeing an experimenter act on the object. They gave the children fMRI scans after learning, and found that a child's motor system was recruited when listening to the word only if learning had involved self-generated actions on the objects. Moving the body leads to sensorimotor representations, which may be important for learning. As gesture too is an act of the body, it may gain some (but not all, see Novack, Congdon, Hemani-Lopez, & Goldin-Meadow, 2014) of its power as a learning mechanism from its roots in action.

Gesture may also be important in learning because it offers the learner a second representational format, one that is more gradient and imagistic than the discrete and categorical representational format provided by speech. Evidence for this possibility comes from the fact that gesture–sign combinations predict learning on a math task in deaf children, just as gesture–speech combinations do in hearing children (Goldin-Meadow, Shield, Lenzen, Herzig, & Padden, 2012). Unlike gesture–speech combinations, which use two different modalities (hand and mouth), gesture–sign combinations use only one modality (hand). However, gesture–sign combinations are comparable to gesture–speech combinations in providing two representational formats – a gradient, imagistic format in gesture and a discrete, categorical format in speech or sign. Future work is needed to determine whether gesture–sign combinations play the same role in language learning as gesture–speech combinations do.

3.2. Using linguistic input to learn language

Usage-based theories of language acquisition hold that children acquire language by applying general learning skills to patterns in their linguistic input. For example, according to Tomasello (2005, p. 186), "children construct from their experience with a particular language some kinds of grammatical categories, based on the function of particular words and phrases in particular utterances – followed by generalisations across these" (see also Bybee & McClelland, 2005; Goldberg & Del Giudice, 2005).

The findings described in the second half of this review lend some support to these accounts. Variations in both the quantity and quality of the linguistic input to which children are exposed predict variations in child outcomes. Interestingly, input can play different roles in predicting child outcome depending upon which linguistic property is being learned (e.g., vocabulary or syntax) and who is doing the learning (e.g., whether the learner does or does not have brain injury). Finding a relation between variations in parent input and variations in child output does not, of course, tell us *how* the input is used by the language-learning child. Beginning with Saffran, Aslin, and Newport's (1996) seminal paper applying statistical learning to language learning, extensive work has been done exploring the processes by which children accumulate descriptive statistics about their linguistic input and use those statistics to chunk the speech stream into units. Statistical learning is one of the processes that children apply to their linguistic input to discover the structures of their language.

However, the homesign findings described in the first half of this review make it clear that accounts of language learning that focus centrally on linguistic input tell only part of the story. A strict usage-based account would have to predict that, in the absence of linguistic input, a child would not communicate in language-like ways since there would be no input from which to glean linguistic patterns. This prediction fails – homesign, which is developed in the absence of linguistic input, contains many of the properties found in natural language (Goldin-Meadow, 2003a). Moreover, the fact that children are excellent statistical learners does not explain how homesigners can incorporate structures into their gestures that resemble natural language (but do *not* resemble the co-speech gestures their hearing parents use with them, Goldin-Meadow & Mylander, 1983, 1998). Nor does it explain why learners sometimes change the linguistic input to which they are exposed (input from either a natural or an artificial language, e.g., Fedzechkina, Jaeger, & Newport, 2012).

Rather than being extracted from linguistic input, the properties found in homesign appear to be imposed on human language by the communicator. They are thus good candidates for innate structures that guide the process of language learning. The homesign data do not tell us whether these structures are specific to language learning or more general cognitive structures that are applied to language even when there is no explicit model for doing so. The homesign data do, however, make it clear that children bring their own biases to language. These biases are difficult to see under typical language-learning circumstances, but are put into bold relief when children, such as homesigners, are not exposed to linguistic input. If the structures that are characteristic of natural language appear in homesign, we then have good evidence that those structures are part of human language not only because they have been handed down from generation to generation, but also because this is the way humans are innately biased to structure their communication.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

This work was supported by NIDCD (R01 DC00491), NSF (BNS 8497941), NICHD (P01 HD 40605), NICHD (R01-HD47450) and NSF (SBE 0541957 to the Spatial Intelligence and Learning Center, SGM is a co-PI).

Note

1. The gestures that parents or teachers produce can also influence learning, either by conveying new information in an accessible modality (e.g., Singer & Goldin-Meadow, 2005), or by providing a model for gesturing that encourages children to gesture themselves (e.g., Cook & Goldin-Meadow, 2006).

References

Abner, N., Namboodiripad, S., Spaepen, L., & Goldin-Meadow, S. (2015). Emergent morphology in child homesign: Evidence from number language. In preparation.

Allan, K. (1997). Classifiers. *Language*, *53*, 285–311. doi:10.1353/lan.1977.0043

Applebaum, L., Coppola, M., & Goldin-Meadow, S. (2014). Prosody in a communication system developed without a language model. *Sign Language and Linguistics*, *17*, 181–212. doi:10.1075/sll.17.2.02app

Barsalou, L. W. (1999). Perceptual symbols systems. *Behavioral and Brain Sciences*, *22*, 577–660.

Bates, E. (1976). *Language and context: The acquisition of pragmatics*. New York, NY: Academic Press.

Bates, E., Thal, D., Trauner, D., Fenson, J., Aram, D., Eisele, J., & Nass, R. (1997). From first words to grammar in children with focal brain injury. *Developmental Neuropsychology, 13*, 275–343. doi:10.1080/87565649709540682

Benedicto, E., & Brentari, D. (2004). Where did all the arguments go? Argument-changing properties of classifiers in ASL. *Natural Language and Linguistic Theory*, *22*, 743–810. doi:10.1007/s11049-003-4698-2

Brentari, D., Coppola, M., Mazzoni, L., & Goldin-Meadow, S. (2012). When does a system become phonological? Handshape production in gesturers, signers, and homesigners. *Natural Language and Linguistic Theory*, *30*(1), 1–31. doi:10.1007/s11049-011-9145-1

Broaders, S. C., Cook, S. W., Mitchell, Z., & Goldin-Meadow, S. (2007). Making children gesture brings out implicit knowledge and leads to learning. *Journal of Experimental Psychology: General*, *136*, 539–550. doi:10.1037/0096-3445.136.4.539

Butcher, C., & Goldin-Meadow, S. (2000). Gesture and the transition from one-to two-word speech: When hand and mouth come together. In D. McNeill (Ed.), *Language and gesture* (pp. 235–257). New York, NY: Cambridge University Press.

Butcher, C., Mylander, C., & Goldin-Meadow, S. (1991). Displaced communication in a self-styled gesture system: Pointing at the non-present. *Cognitive Development*, *6*, 315–342. doi:10.1016/0885-2014(91)90042-C

Bybee, J., & McClelland, J. L. (2005). Alternatives to the combinatorial paradigm of linguistic theory based on domain general principles of human cognition. *The Linguistic Review, 22*, 381–410. doi:10.1515/tlir.2005.22.2-4.381

Cartmill, E. A., Armstrong, B. F., Gleitman, L. R., Goldin-Meadow, S., Medina, T. N., & Trueswell, J. C. (2013). Quality of early parent input predicts child vocabulary three years later. *Proceedings of the National Academy of Sciences*, *110*, 11278–11283. doi:10.1073/pnas.1309518110

Cartmill, E. A., Hunsicker, D., & Goldin-Meadow, S. (2014). Pointing and naming are not redundant: Children use gesture to modify nouns before they modify nouns in speech. *Developmental Psychology*, *50*, 1660–1666. doi:10.1037/a0036003

Chomsky, N. (1999). On the nature, use, and acquisition of language. In W. C. Ritchie & T. K. Bhatia (Eds.), *Handbook of child language acquisition* (pp. 33–54). New York, NY: Academic Press.

Cinque, G. (2013). Cognition, universal grammar, and typological generalizations. *Lingua*, *130*, 50–65. doi:10.1016/j.lingua.2012.10.007

Cook, S. W., & Goldin-Meadow, S. (2006). The role of gesture in learning: Do children use their hands to change their minds? *Journal of Cognition and Development, 7*, 211–232. doi:10.1207/s15327647jcd0702_4

Coppola, M., & Newport, E. L. (2005). Grammatical subjects in homesign: Abstract linguistic structure in adult primary gesture systems without linguistic input. *Proceedings of the National Academy of Sciences*, *102*, 19249–19253. doi:10.1073/pnas.0509306102

Coppola, M., & Senghas, A. (2010). The emergence of deixis in Nicaraguan signing. In D. Brentari (Ed.), *Sign languages: A Cambridge language survey* (pp. 543–569). Cambridge: Cambridge University Press.

Coppola, M., Spaepen, E., & Goldin-Meadow, S. (2013). Communicating about quantity without a language model: Number devices in homesign grammar. *Cognitive Psychology*, *67*(1–2), 1–25. doi:10.1016/j.cogpsych.2013.05.003

Demir, O. E., Levine, S. C., & Goldin-Meadow, S. (2010). Narrative skill in children with early unilateral brain injury: A possible limit to functional plasticity. *Developmental Science, 13*, 636–647. doi:10.1111/j.1467-7687.2009.00920.x

Demir, O. E., Levine, S., & Goldin-Meadow, S. (2014). A tale of two hands: Children's gesture use in narrative production predicts later narrative structure in speech. *Journal of Child Language*. Advance online publication. doi:10.1017/S0305000914000415

Farkas, G., & Beron, K. (2004). The detailed age trajectory of oral vocabulary knowledge: Differences by class and race. *Social Science Research*, *33*, 464–497. doi:10.1016/j.ssresearch.2003.08.001

Fedzechkina, M., Jaeger, T. F., & Newport, E. L. (2012). Language learners restructure their input to facilitate efficient communication. *Proceedings of the National Academy of Sciences, 109*, 17897–17902. doi:10.1073/pnas.1215776109

Feldman, H. M. (2005). Language learning with an injured brain. *Language Learning and Development, 1*, 265–288. doi:10.1080/15475441.2005.9671949

Feldman, H., Goldin-Meadow, S., & Gleitman, L. (1978). Beyond Herodotus: The creation of language by linguistically deprived deaf children. In A. Lock (Ed.), *Action, symbol, and gesture: The emergence of language* (pp. 351–414). New York, NY: Academic Press.

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thal, D. J., & Pethick, S. J., … Stiles, J.(1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development*, *59*(5), 1–185. doi:10.2307/1166093

Franklin, A., Giannakidou, A., & Goldin-Meadow, S. (2011). Negation, questions, and structure building in a homesign system. *Cognition*, *118*, 398–416. doi:10.1016/j.cognition.2010.08.017

Fusellier-Souza, I. (2006). Emergence and development of sign languages: From a semiogenetic point of view. *Sign Language Studies*, *7*(1), 30–56. doi:10.1353/sls.2006.0030

Gillette, J., Gleitman, H., Gleitman, L., & Lederer, A. (1999). Human simulations of vocabulary learning. *Cognition*, *73*(2), 135–176. doi:10.1016/S0010-0277(99)00036-0

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin and Review, 9*, 558–565. doi:10.3758/BF03196313

Goldberg, A. E., & Del Giudice, A. (2005). Subject-auxiliary inversion: A natural category. *The Linguistic Review, 22*, 411–428. doi:10.1515/tlir.2005.22.2-4.411

Goldin-Meadow, S. (1982). The resilience of recursion: A study of a communication system developed without a conventional language model. In E. Wanner & L. R. Gleitman (Eds.), *Language acquisition: The state of the art* (pp. 51–77). New York, NY: Cambridge University Press.

Goldin-Meadow, S. (2003a). *The resilience of Language.* New York, NY: Psychology Press.

Goldin-Meadow, S. (2003b). *Hearing gesture: How our hands help us think*. Cambridge, MA: Harvard University Press.

Goldin-Meadow, S., Brentari, D., Coppola, M., Horton, L., & Senghas, A. (2015) Watching language grow in the manual modality: Nominals, predicates, and handshapes. *Cognition*, *136*, 381–395. doi:10.1016/j.cognition.2014.11.029

Goldin-Meadow, S., & Butcher, C. (2003). Pointing toward two-word speech in young children. In S. Kita (Ed.), *Pointing: Where language, culture, and cognition meet* (pp. 85–107). Hillsdale, NJ: Erlbaum.

Goldin-Meadow, S., Cook, S. W., & Mitchell, Z. A. (2009). Gesturing gives children new ideas about math. *Psychological Science, 20*, 267–272. doi:10.1111/j.1467-9280.2009.02297.x

Goldin-Meadow, S., & Feldman, H. (1977). The development of language-like communication without a language model. *Science*, *197*, 401–403. doi:10.1126/science.877567

Goldin-Meadow, S., Goodrich, W., Sauer, E., & Iverson, J. (2007). Young children use their hands to tell their mothers what to say. *Developmental Science*, *10*, 778–785. doi:10.1111/j.1467-7687.2007.00636.x

Goldin-Meadow, S., Levine, S. C., Hedges, L. V., Huttenlocher, J., Raudenbush, S. W., & Small, S. L. (2014). New evidence about language and cognitive development based on a longitudinal study: Hypotheses for intervention. *American Psychologist*, *69*, 588–599. doi:10.1037/a0036886

Goldin-Meadow, S., & Mylander, C. (1983). Gestural communication in deaf children: The non-effects of parental input on language development. *Science, 221*, 372–374. doi:10.1126/science.6867713

Goldin-Meadow, S., & Mylander, C. (1984). Gestural communication in deaf children: The effects and non-effects of parental input on early language development. *Monographs of the Society for Research in Child Development*, *49*(3/4), 1–151.

Goldin-Meadow, S., & Mylander, C. (1998). Spontaneous sign systems created by deaf children in two cultures. *Nature, 91*, 279–281. doi:10.1038/34646

Goldin-Meadow, S., Mylander, C., & Butcher, C. (1995). The resilience of combinatorial structure at the word level: Morphology in self-styled gesture systems. *Cognition*, *56*, 195–262. doi:10.1016/0010-0277(95)00662-I

Goldin-Meadow, S., Mylander, C., & Franklin, A. (2007). How children make language out of gesture: Morphological structure in gesture systems developed by American and Chinese deaf children. *Cognitive Psychology, 55*(2), 87–135. doi:10.1016/j.cogpsych.2006.08.001

Goldin-Meadow, S., Namboodiripad, S., Mylander, C., Ozyurek, A., & Sancar, B. (2015). The resilience of structure built around the predicate: Homesign gesture systems in Turkish and American deaf children. *Journal of Cognition and Development*, *16*(1), 55–80. doi:10.1080/15248372.2013.803970

Goldin-Meadow, S., Shield, A., Lenzen, D., Herzig, M., & Padden, C., (2012). The gestures ASL signers use tell us when they are ready to learn math. *Cognition*, *123*, 448–453. doi:10.1016/j.cognition.2012.02.006

Greenfield, P., & Smith, J. (1976). *The structure of communication in early language development*. New York, NY: Academic Press.

Hart, B., & Risley, T. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore, MD: Brookes.

Heath, S. B. (1983). *Ways with words*. Cambridge: Cambridge University Press.

Hess, R. D., & Shipman, V. C. (1965). Early experience and the socialization of cognitive modes in children. *Child Development, 36*, 869–886. doi:10.2307/1126930

Hoff, E. (2006). How social contexts support and shape language development. *Developmental Review*, *26*(1), 55–88. doi:10.1016/j.dr.2005.11.002

Hoff-Ginsberg, E. (1990). Maternal speech and the child's development of syntax: A further look. *Journal of Child Language, 17*(01), 85–99. doi:10.1017/S0305000900013118

Horton, L., Goldin-Meadow, S., & Brentari, D. (2014). *Tracing the path to sign: Formal properties of movement in gesture, homesign and sign language*. Paper presentation at the International Conference of the Society for Gesture Studies. University of California, San Diego, CA.

Hunsicker, D., & Goldin-Meadow, S. (2012). Hierarchical structure in a self-created communication system: Building nominal constituents in homesign. *Language*, *88*, 732–763. doi:10.1353/lan.2012.0092

Huttenlocher, J., Haight, W., Bryk, A., Selzer, M., & Lyons, T. (1991). Early vocabulary growth: Relation to language input and gender. *Developmental Psychology, 27*, 236–248. doi:10.1037/0012-1649.27.2.236

Huttenlocher, J., Vasilyeva, M., Cymerman, E., & Levine, S. (2002). Language input and child syntax. *Cognitive Psychology, 45*, 337–374. doi:10.1016/S0010-0285(02)00500-5

Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., & Hedges, L. V. (2010). Sources of variability in children's language growth. *Cognitive Psychology, 61*, 343–365. doi:10.1016/j.cogpsych.2010.08.002

Iverson, J. M., & Goldin-Meadow, S. (1998). Why people gesture as they speak. *Nature*, *396*, 228. doi:10.1038/24300

Iverson, J. M., & Goldin-Meadow, S. (2005). Gesture paves the way for language development. *Psychological Science*, *16*, 367–371. doi:10.1111/j.0956-7976.2005.01542.x

James, K. H., & Swain, S. N. (2011). Only self-generated actions create sensori-motor systems in the developing brain. *Developmental Science, 14*, 673–678. doi:10.1111/j.1467-7687.2010.01011.x

Klatzky, R. L., McCloskey, B., Doherty, S., Pellegrino, J. W., & Smith, T. (1987). Knowledge about hand shaping and knowledge about objects. *Journal of Motor Behavior*, *19*, 187–213. doi:10.1080/00222895.1987.10735407

LeBarton, E. S., Raudenbush, S., & Goldin-Meadow, S. (2013). Experimentally-induced increases in early gesture lead to increases in spoken vocabulary. *Journal of Cognition and Development*. doi10.1080/15248372.2013.858041

Lederman, S. J., & Klatzky, R. L. (1987). Hand movements: A window into haptic object recognition. *Cognitive Psychology*, *19*, 342–368. doi:10.1016/0010-0285(87)90008-9

Lederman, S. J., & Klatzky, R. L. (1990). Haptic classification of common objects: Knowledge-driven exploration. *Cognitive Psychology*, *22*, 421–459. doi:10.1016/0010-0285(90)90009-S

Levine, S. C., Huttenlocher, P., Banich, M. T., & Duda, E. (1987). Factors affecting cognitive functioning of hemiplegic children. *Developmental Medicine and Child Neurology, 29*(1), 27–35. doi:10.1111/j.1469-8749.1987.tb02104.x

Lillo-Martin, D. (1999). Modality effects and modularity in language acquisition: The acquisition of American Sign Language. In W. C. Ritchie & T. K. Bhatia (Eds.), *The handbook of child language acquisition* (pp. 531–567). New York, NY: Academic Press.

MacWhinney, B., Feldman, H., Sacco, K., & Vaaldes-Perez, R. (2000). Online measures of basic language skills in children with early focal brain lesions. *Brain and Language*, *71*, 400–431. doi:10.1006/brln.1999.2273

Marchman, V. A., Miller, R., & Bates, E. (1991). Babble and first words in children with focal brain injury. *Applied Psycholinguistics, 12*(01), 1–22. doi:10.1017/S0142716400009358

McNeill, D. (1992). *Hand and mind*. Chicago, IL: University of Chicago Press.

Miller, J. F., & Chapman, R. S. (1981). The relation between age and mean length of utterance. *Journal of Speech and Hearing Research, 24*, 154–161. doi:10.1044/jshr.2402.154

Morford, J. P., & Goldin-Meadow, S. (1997). From here to there and now to then: The development of displaced reference in homesign and English. *Child Development, 68*, 420–435. doi:10.2307/1131669

Newport, E. L., & Meier, R. P. (1985). The acquisition of American Sign Language. In D. I. Slobin (Ed.), T*he cross-linguistic study of language acquisition, Vol. 1: The data* (pp. 881–931). Hillsdale, NJ: Erlbaum.

Novack, M. A., Congdon, E. L., Hemani-Lopez, N., & Goldin-Meadow, S. (2014). From action to abstraction: Using the hands to learn math. *Psychological Science*, 25, 903–910. doi:10.1177/0956797613518351

Pinker, S. (1984). *Language learnability and language development*. Cambridge, MA: Harvard University Press.

Pinker, S. (1989). *Learnability and cognition: The acquisition of argument structure*. Cambridge, MA: MIT Press.

Rowe, M. L., & Goldin-Meadow, S. (2009a). Differences in early gesture explain SES disparities in child vocabulary size at school entry. *Science*, *323*, 951–953. doi:10.1126/science.1167025

Rowe, M. L., & Goldin-Meadow, S. (2009b). Early gesture selectively predicts later language learning. *Developmental Science*, *12*, 182–187. doi:10.1111/j.1467-7687.2008.00764.x

Rowe, M. L., Levine, S. C., Fisher, J. A., & Goldin-Meadow, S. (2009). Does linguistic input play the same role in language learning for children with and without early brain injury? *Developmental Psychology, 45*(1), 90–102. doi:10.1037/a0012848

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science*, *274*, 1926–1928. doi:10.1126/science.274.5294.1926

Sauer, E., Levine, S. C., & Goldin-Meadow, S. (2010). Early gesture predicts language delay in children with pre- or perinatal brain lesions. *Child Development, 81*, 528–539. doi:10.1111/j.1467-8624.2009.01413.x

Schembri, A. (2003). Rethinking 'classifiers' in signed languages. In K. Emmorey (Ed.), *Perspectives on classifier constructions in sign languages* (pp. 3–34). Mahwah, NJ: Erlbaum Associates.

Senghas, A. (1995). Children's contribution to the birth of Nicaraguan Sign Language (Unpublished Ph.D. dissertation). Massachusetts Institute of Technology, Cambridge, MA.

Senghas, A. (2003). Intergenerational influence and ontogenetic development in the emergence of spatial grammar in Nicaraguan Sign Language. *Cognitive Development, 18*, 511–531. doi:10.1016/j.cogdev.2003.09.006

Singer, M. A., & Goldin-Meadow, S. (2005). Children learn when their teachers' gestures and speech differ. *Psychological Science*, *16*(2), 85–89. doi:10.1111/j.0956-7976.2005.00786.x

Stiles, J., Reilly, J. S., Levine, S. C., Trauner, D., & Nass, R. D. (2012). *Neural plasticity and cognitive development: Insights from children with perinatal brain injury*. New York, NY: Oxford University Press.

Takahashi, E. (1966). Growth and environmental factors in Japan. *Human Biology*, *38*(2), 112–130.

Talmy, L. (1988). The relation of grammar to cognition. In B. Rudzka-Ostyn (Ed.), *Topics in cognitive linguistics* (pp. 166–205). Philadelphia, PA: John Benjamins.

Tomasello, M. (2005). Beyond formalities: The case of language acquisition. *The Linguistic Review, 22*, 183–197. doi:10.1515/tlir.2005.22.2-4.183

Vygotsky, L. (1986). *Thought and language*. Cambridge, MA: The MIT Press.

Weckerly, J., Wulfeck, B., & Reilly, J. (2004). The development of morphosyntactic ability in atypical populations: The acquisition of tag questions in children with early focal lesions and children with specific-language impairment. *Brain and Language*, *88*, 190–201. doi:10.1016/S0093-934X(03)00098-1

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*, 625–636. doi:10.3758/BF03196322