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Gesture links language and cognition for spoken and signed languages

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Abstract

Human communication combines language with gesture. Gesture contributes to human's unique ability to communicate about an infinite number of ideas in an efficient way and to generate representations that are useful for thinking. Gesture and language can be distinguished by distinct underlying modes of thinking and by gradations of conventionalization and the transparency of form-meaning relations. However, it is not always possible or useful to draw a sharp line between gesture and language. In this Review, we first describe how speakers and signers produce facial, manual, and body gestures. Then we describe how representational gesture encodes information, considering constraints from properties of languages, and how speakers and signers orchestrate language and gesture. Next, we review how gesture production shapes thinking for both signers and speakers. Then we consider gesture comprehension and how the meaning of gestures is integrated with language. We conclude with suggestions for further exploration of gesture as a critical part of the human mind.

[H1] Introduction

Humans can communicate an infinite variety of new ideas that come to their mind, and can refer to things that are not in the here-and-now. This communication system is also useful for thinking because it is an excellent way to mentally represent the world[1-4]. Traditionally, language alone was given full credit for this impressive expressive power and cognitive benefit[2,5,6]. However, human communication is inherently 'multi-modal'[7-17], comprising multiple modes of representation, most notably language and gesture.

Gesture—just like language—can express an infinite variety of ideas[10], refer to things not in the here-and-now[18], and benefit cognition[19]. However, language and gesture do so in qualitatively different ways. Language primarily expresses ideas using conventionalized form-meaning mappings, whereas gesture typically expresses ideas using idiosyncratic depiction and indication. Gesture can accompany spoken language and signed language. Sign languages are diverse, full-fledged languages that use conventionalized movements of the body and face to encode the linguistic message (Box 1). By convention, signs are written using a spoken language translation equivalent with capital letters, such as GIRL. The hyperlinks in this article are to videos of American Sign Language from the ASL-LEX database [20,21] or to videos of other sign languages from SpreadTheSign. Regardless of whether language is spoken or signed, gesture and language complement each other and enrich human communication and thinking.

In this Review, we discuss how gesture, together with language, supports communication and thinking. We first describe what types of gestures accompany spoken and signed languages, and how gesture can be distinguished from language. We then discuss how language and gesture are produced in a coordinated way to meet the communicative and cognitive needs of the language producer. Finally, we discuss what type of information the recipient gleans from gesture and how the recipient integrates information from language and gesture to derive the message of the language producer.

[H1] Co-speech and co-sign gesture

Gestures that accompany signed or spoken language are mainly categorised based on their form-meaning relationships[10,22-24]. Because co-sign gestures use the same physical channel as signed languages and are often tightly coupled with language, it is more challenging to identify co-sign than co-speech gestures.

[H2] Types of gesture

Different types of gestures might be processed by different psychological mechanisms, and distinguishing between gesture types will help to sharpen our discussion about the difference between gesture and language. Gestures that depict movement, bodily action, or object shape are examples of iconic gesture[10]. Metaphorical gestures use the body and space to depict abstract concepts[9,25]; for example, a sweeping hand movement from left to right can represent the passage of time. Deictic (pointing) gestures indicate a location or direction in space or in the surrounding environment[26]. These three types of gesture (iconic, metaphorical, and deictic) all flexibly change their form in accordance with the referent. For example, when a gesture with the extended index finger traces how a ball bounced across a room, the manner and direction of the finger movement reflects how and where the event took place. Some researchers subsume these gesture types in one category: representational gestures[27]. Gestures can also be emblems, which express certain concepts by virtue of a conventionalized gesture form, such as the 'OK' gesture with a ring formed by the thumb and index finger[10,24,28]. Another category is pragmatic (or interactive, recurrent) gestures, which regulate on-going interaction by expressing information such as topic-comment structure, uncertainty of verbalized information, and specification of who is being addressed[22,29,30]. For example, shrugging shoulders to indicate uncertainty or lack of interest is an interactive gesture.

These types of gesture can accompany communication in spoken and signed languages[31,32]. However, one type of gesture that can accompany spoken language but not a signed language is beat gestures[10], in which the hand makes a small up and down movement often multiple times as if to mark the rhythm of prosodic peaks in speech[33]. Because sign and gesture are both produced manually, it is not clear how to distinguish beat gestures from hand or other body movements that convey linguistic rhythm (prosody)[34]. Speech rhythms can be marked both vocally (for example, by stressed syllables) and manually by beat gestures, whereas sign rhythms are marked only in one physical channel, via movements of the hands and/or body.

These gesture types are not mutually exclusive[8]; a given gesture can be a composite of different types. For example, a gesture might iconically depict a shape (for example, tracing an outline with an extended finger) and deictically point to something at the same time (for example, by directing the gesture towards an object).

[H2] Separating gesture from sign

For gestures produced simultaneously with speech (co-speech gestures), language and gesture use different physical channels, and therefore it is easy to separate language from gesture. Similar to co-speech gestures, co-sign gestures are produced simultaneously with signing. Because sign language and co-sign gesture both use the same physical channel, they need to be distinguished by other properties. Various characteristics have been proposed to distinguish between signs and representational gestures (Table 1).

Co-sign iconic gestures can take several forms. For example, signers can produce whole-body gestures to illustrate movements of the body that co-occur with the action expressed by manual signs, such as swaying back and forth to depict waltzing while signing DANCE or rocking back and forth while producing the verb form of ROCKING-CHAIR in American Sign Language[31]. Such whole-body movements are considered gestures rather than signs because they are idiosyncratic, optional, and violate sign form constraints (signing typically does not involve movements of the full body). Signers can also produce iconic facial gestures that depict aspects of a scene, for example, a signer of Israeli Sign Language produced pursed lips and sucked-in cheeks while signing ‘climb up’ to suggest squeezing into a small space (climbing up a drainpipe) or puffed out their cheeks to depict the large size of an object[35]. Like speakers, signers also produce affective facial gestures (for example, expressions of surprise, anger, suspicion, etc.) to depict the emotional states of characters in a narrative. Another type of iconic co-sign gesture is when the signer modifies the form of a manual sign for illustrative purposes. For example, signers can modify the movement of a verb to depict the speed of an action (slow or fast) or modify a handshape to depict the size of an object (for example, a large or small round object)[36,37]. Signs can also be gesturally modified[38]. For example, the sign BOX in American Sign Language can be produced within a larger space than the standard form to depict a large box. Co-sign gestures that change the form of a sign are akin to vocal gestures in which a speaker modifies the sound of a word to depict aspects of an event, such as extending the word ‘long’ to ‘looooong’ or saying ‘up and down’ with a rising and falling intonation[39].

Co-sign gesture can also be deictic, as when a sign is directed toward something or someone in the environment. For example, pronouns are directed toward the location of the referent when it is present in the environment. In many sign languages, the type of pronoun is linguistically determined by handshape, for example in American Sign Language where an index finger is used for YOU, a flat hand for YOUR, a thumbs-up handshape for

YOURSELF (Fig. 1). However, the precise direction of the pronominal sign is gestural and determined by where the referent (or addressee) is located in the environment[40,41].

Pointing signs like YOU differ from pointing gestures produced by speakers because they are more consistent in form (more conventionalized), shorter in duration, and their duration is influenced by linguistic structure (for example, they are longer at the end of a phrase)[42]. Another critical difference between co-sign and co-speech deictic gesture is that spoken words themselves cannot point, but many signs can be directed toward locations in the environment. For example, the American Sign Language sign SAME can be produced by moving the sign between two objects to indicate that they are the same. Such examples are termed environmentally-coupled signs [43] because they are parallel to environmentally-coupled co-speech gestures [44-46], which cannot be understood without considering the environment to which they are tied.

In addition to pronouns, signers direct certain verbs (so-called indicating verbs) toward the location of a referent in the environment. For example, to express 'I'll email you,' a signer would direct the verb form of E-MAIL toward the person they will be emailing. Across different sign languages, pronouns and indicating verbs are argued to represent a fusion of linguistic and deictic gestural elements[40,41,47,48] (for critique of this approach see[49]). The sign is linguistic (stored in the mental dictionary) and the direction of the sign is gestural, functioning like a pointing gesture that accompanies speech.

Just as all speakers are thought to gesture, all signers are likely to gesture as well. The use of deictic co-sign gesture is expected to be universal given the embodied and spatial nature of sign languages. Constructed action also occurs frequently across sign languages and typically involves face and body co-sign gesture. Constructed action is when a signer (or speaker) reports the actions of another and produces gestures to accompany their signing (or speaking) that depict the facial expression, eye gaze, and head or body movements of the person whose actions are being described. For instance, in telling a story about someone frantically searching for a lost item on the ground, the signer might produce the American Sign Language sign LOOK-FOR with a repeated, exaggerated movement (to gesturally depict effortful searching), while looking downward with an anxious facial expression. However, whether and how co-sign gestures vary in frequency or in type across signers and across sign languages is currently unknown.

[H1] Distinguishing gesture and language

Most researchers recognize gesture as a means of communication distinct from spoken and signed language, although some do not[50]. However, researchers vary greatly as to how they define gesture in relation to language[10,32,41,51]. Drawing from these approaches, we argue that gesture and language differ from each other along three conceptual dimensions: modes of thinking, conventionalization, and transparency of meaning. Existing definitions of gesture reflect different emphasis on these dimensions, resulting in different boundaries between gesture and language. The dimension of modes of thinking concerns the type of thoughts expressed, and the dimensions of conventionalization and transparency concern how form and meaning are related to each other. These three dimensions can distinguish among different types of gestures, some of which are more similar to language than others.

[H2] Modes of thinking

Gesture and language differ in the underlying mode of thinking. The human mind represents and processes information in multiple ways. For instance, some cognitive psychology theories contrast visuo-spatial and verbal representations[52,53]. Visuo-spatial representations are analogue (continuous) and imagistic in the sense that the mental representation retains some similarity to the entity in the world that is represented. By contrast, verbal representations are digital (categorical) and propositional in the sense that the mental representation is abstracted away from the specific entity in the world.

Following this approach, theories of gesture contrast two qualitatively different mental representations that underlie representational gesture (iconic, deictic, and metaphorical) and language. Specifically, representational gestures reflect imagistic mental representations[10,27,54-58]. The imagery underlying representational gestures arises from spatio-motoric thinking, based on how the body interacts with the real and imagined environment[27,57,58]. How the body moves through space provides a focus and structure in these spatial representations. Unlike representational gestures, language can reflect propositional mental representations, referred to as analytic thinking[10,26,27,32,55]. Thus, language can encode both imagistic and propositional mental representations[57-59]. When people produce language and representational gesture together in a semantically coordinated way, they are capturing related aspects of reality using two different modes of thinking[27]. An idea can even be a composite of the two modes of thinking[10].. For example, when the speaker says, 'we had to go through the process,' while producing a gesture in which the hand repeatedly rotates at the wrist, a series of events are conceptualised at an abstract level with the word 'process' and in an imagistic way with the gesture, highlighting the small (insignificant) and repetitive nature of the events.

In contrast to representational gestures, emblem gestures (for example, the thumbs-up gesture) often function like words in that they can replace a word or phrase in a sentence[60]. Such gestures reflect propositional mental representations in analytic thinking, just as words and phrases in language do. Thus, language and gesture differ in their modes of thinking that conceptualise the world in qualitatively different ways.

[H2] Conventionalization

Gesture and language differ in the degree of conventionalization. Language consists of symbols in which form and meaning are associated with each other largely by convention, that is, agreement among members of a linguistic community. Thus, linguistic forms for a given meaning typically differ across languages[61] (Box 1). Even words and signs in which the form resembles the meanings are conventionalized differently in different languages. For example, a dog's barking is 'bow wow' in English, and 'wan wan' in Japanese; the sign BIRD in American Sign Language depicts a bird's beak, whereas the sign BIRD in Turkish Sign Language depicts a bird's wings.

Gesture types have different degrees of conventionalization. Representational gestures contrast with language most clearly: individuals produce distinct gestures to idiosyncratically depict events, shapes, or indicate directions. By contrast, some cultures have conventions for some elements of deictic gestures. For example, across cultures, a pointing gesture can be produced with the hand, the lips[62-64] (Fig. 2A), or the nose[65]. In addition, specific handshapes can be used for specific types of referents, for example, a palm-down flat handshape to point to multiple scattered objects versus a handshape with the index-finger extended to point to a single object[64] (Fig. 2B). A partial conventionalization can be also seen in so-called families of gestures, where a core form feature is associated with a specific meaning and other context-specific form features are added to create context-specific meaning[8,30,66,67]. For example, a palm-up open hand can be used to encode meaning related to offering or receiving, and pointing to the addressee with palm-up open hand can indicate that the gesturer accepts what the addressee has said (Fig. 2C). The core form-meaning association in such gesture families are culture-specific[68]. Emblems (for example, the 'money' gesture in Japan; Fig. 2D) are the most strongly conventionalized and show little form variation across contexts, but do vary by culture[28].

For language, form and meaning are associated by convention which differs across linguistic communities, even when the association is relatively transparent. For gesture, conventionalization is much more restricted, occurring only for some deictic and emblematic gestures.

[H2] Transparency

Another important dimension in which gesture and language differ is the transparency of form-meaning mappings. Spoken and signed languages have largely opaque form-meaning mappings in that if one does not know the language, it is difficult to guess what a particular word or sentence means[61]. Indeed, the meaning of a sign is rarely guessed correctly by someone who does not know the sign language[69,70].

Despite being a conventionalized communication system, languages have certain forms with meanings that are understandable to some extent by those who do not know the language[20,71-73]. This property is mainly owing to iconicity, or a resemblance between the form and meaning. Degree of iconicity varies across both signed and spoken languages[74]. Words in sign languages often contain some degree of iconicity[75]. For example, the signs DRINK and CRY in American Sign Language strongly resemble aspects of the actions they denote, and their meanings are easily guessed by non-signers[70]. However, the sign CRY in Danish Sign Language is produced at the neck and is much less iconic than in American Sign Language. Some spoken languages, like Japanese and Yoruba, have many more iconic words ('ideophones') than Indo-European languages[76]. Examples from Japanese include *gorogoro* (a heavy object moving repeatedly) and *pika* (a flash of light). Onomatopoetic words such as *buzz*, *clang*, and *gurgle*, are examples of iconic words in English.

Gestures can have more transparent form-meaning mappings than words and signs. However, the degree of transparency depends on the gesture type. Representational gestures that are least bound by conventions are most transparent because their depictive nature and deictic properties make their meanings easier to decode. Nonetheless, the degree of transparency greatly varies even among representational gestures[77]. Similar to most spoken words and signs, emblems can be highly opaque in their meanings (Fig. 2D)[28].

Although some signs and words have a transparent mapping between their form and meaning, most do not. The reverse pattern holds for gesture – for most gestures, the form bears a resemblance to the meaning, but there are some exceptions, such as emblems.

[H2] Interplay between the factors

The three dimensions that distinguish language and gesture are not totally independent from each other (Table 2). Language and gesture both use two powerful tools for sharing ideas: convention and transparency. Language and gesture differ in the degree to which these tools are used. Analytic thinking is based on abstract amodal representations; therefore, when one wishes to communicate about the content of analytic thinking, because it is difficult to express abstract amodal representations in an iconic and transparent way, a conventionalized communication system such as language is most appropriate. By contrast, spatio-motoric content (for example, how to grasp a particular object, which highlights its size and shape) can be communicated by non-conventionalized representational gestures or by conventionalized linguistic expressions. Non-conventionalized communication signals are relatively transparent to the recipient, but conventionalized signals can be either transparent or opaque. Overall, representational gestures, based on spatio-motoric thinking and expressed by non-conventionalized transparent signals, contrast most starkly to language in comparison to beat gestures and emblems.

Because the three conceptual dimensions distinguishing language and gesture interact with each other in a complex way, and both gesture and language consist of different types of communicative signals, we argue that it is not useful to draw a hard line between language and gesture[78]. This point is particularly clear for sign language, in which language and gesture work together seamlessly to optimize efficient communication of thoughts within the same physical channel. For both signers and speakers, communication requires different types of expressions to efficiently communicate the products of different types of thinking. Furthermore, often a given communicative signal is a composite of different ways of encoding meaning.

Our view contrasts with approaches that draw a sharp line between language and gesture[10,32]. However, it is in line with those who argue that the difference between language and gesture is a matter of degree[51,78,79]. Our view also differs from frameworks that reject any distinction between language and gesture and argue for a holistic theory of face-to-face communication[50,80]. We suggest that a clearer understanding of language and gesture will emerge when researchers recognize the inter-relatedness of the three conceptual dimensions and the composite and graded nature of communicative signals in terms of conventionality and transparency. Our view is also in line with the idea that gesture is 'a part of language' (considering language in the broad sense of human communication) and that gesture and language serve complementary functions[8,10,11].

[H1] Gesture production

Although it is not easy to draw a hard line between language and gesture, representational gesture is arguably the most different from language. Thus, psychological studies on gesture production have focused largely on these gestures, with some notable exceptions[33,81-84]. In this section we discuss how the production of representational gestures relates to language, communication, and cognition.

[H2] Effects of language

Language and representational gesture originate from distinct modes of thinking, but they are produced in a coordinated way. In particular, the specific language one uses shapes the way representational gestures are produced[54]. Thus, language and gesture production processes are not independent from each other, but rather are inter-related[26,27,55-58,85-89].

How representational co-speech gestures depict an event depends on how a language encodes the event using lexical items[54,90-94] and grammatical structures available in the language[54,95-104]. Gestures encode information that is used in one planning unit for speech production[100]. Clauses (the grammatical unit organized around a verb) are a planning unit [105], therefore the grammatical structure of a verb influences gesture production. For example, when describing a motion event (for example, something rolling down a slope), English uses a single clause with one verb ('it rolled down the hill') to express both manner (rolling) and path (down). By contrast, Japanese and Turkish require two clauses with two separate verbs (equivalent to 'it descended the hill, while it rolled')[106]. As a consequence, English speakers can plan to verbalize manner and path within one planning unit, whereas Japanese and Turkish speakers typically need two planning units. Accordingly, English speakers tend to produce a single gesture that simultaneously expresses manner and path (for example, the finger tracing a trajectory that goes diagonally downward with multiple loops), whereas Turkish and Japanese speakers tend produce separate gestures for manner and path (the finger traces a downward path and then multiple loops)[54,96-98]. Furthermore, when English speakers were experimentally led to use one-clause or two-clause descriptions of motion events, they were more likely to produce manner-path simultaneous gestures in one-clause descriptions and separate manner and path gestures in two-clause descriptions[107]. Thus, how language packages different components of an event in a planning unit for speech production determines how semantically related gesture packages information (however, this pattern is not always clear[108]).

Along a similar vein, when spoken languages differ in what aspects of an event are encoded in the word that describes the event, the accompanying iconic gesture depicts events in different ways across languages. For example, the English verb ‘swing’ has no equivalent in Japanese, and when describing an event in which someone swings across a street from one building to another on a rope, English speakers use the verb ‘swing’ and are more likely to produce an arc-only gesture whereas Japanese speakers use a motion verb without trajectory specification such as ‘go’ and are more likely to produce a straight path gesture. Thus, the gesture reflects the information encoded in the word[54,90,91,93]. Finally, gestures reflect the temporal structure of an event when it is specified grammatically (progressive: verb+ing, or perfect: ‘verb+ed’) or lexically (as in the difference between ‘keep verb+ing’ and ‘start to verb’).[109-111] For example, gestures accompanying a sentence with progressive aspect (‘is cycling’) are longer in duration than gestures accompanying a sentence with perfective aspect (‘cycled’)[109].

For sign languages, co-sign gesture is constrained by the form of signs, which vary across languages (Box 1). Specifically, body-anchored signs (signs articulated at or near a location on the body) cannot be deictically directed toward a location, whereas signs articulated in neutral space (the space in front of the signer) can be. For example, American Sign Language signers can direct the sign DOG toward a location in the environment, such as near a picture of a dog in a story book when signing with a child, thereby producing a co-sign deictic gesture. However, the sign DOG in Italian Sign Language is produced at the neck, which prevents signers from adding a co-sign directional gesture. The nature and extent of phonological constraints on co-sign gesture are currently unknown, but it is likely that cross-linguistic differences in sign forms impact how signs can be gesturally modified. For example, the signs for ‘apple’ in American, Spanish, and Czech Sign Languages are all made with a closed fist handshape, but with an open handshape in German, Italian, and British Sign Languages. Signers of the latter but not the former languages might be able to modify the size of the handshape to gesturally depict a very large apple by spreading their fingers wider. More systematic research is needed, but it seems that whether and how co-sign gesture can accompany a sign might be partially dependent on the phonological form of the sign.

For both spoken and signed languages, the linguistic structure of an utterance can constrain the nature and form of the accompanying gestures. Thus, the pattern of gesture production varies in systematic ways across languages.

[H2] Facilitating communication

The division of labour between language and gesture changes depending on communicative needs and contexts. When producing language and gesture, the sender evaluates key elements of communication to determine how communicative labour can be divided between language and gesture. The elements are signal, code, message, and information type. In successful communication, the sender delivers a physical communicative signal, which carries linguistic and/or gestural form to the recipient. A code refers to how form maps to meaning. If the recipient can obtain a clear signal, they can de-code the meaning expressed by the linguistic/gestural form, to infer the sender's message. The message can be about various types of information (for example, information about action, information about spatial relationships). Taking this structure of communication into account, language users produce gestures in varying ways to optimise communication.

The clarity of the communicative signal influences the division of labour between language and gesture, particularly for speakers. When the signal in the spoken language channel is degraded, such as when speaking in a noisy environment, the speaker produces more complex gestures, presumably in an effort to convey more information in gesture[112]. When the visual signal is unavailable, for example, when the speaker and the addressee are separated by a solid barrier, the speaker produces representational gestures at a lower rate[113-119] and less prominently[120,121].

Because co-sign gesture and sign are both produced in the same perceptual channel, they are both impacted by the clarity of the signal, that is, whether the signer and addressee can easily see each other. When visibility is reduced (for example, by a semi-transparent barrier), signers tend to produce slower and larger signing—the manual equivalent of shouting[122,123]. The production of signs, co-sign gesture, and independent gestures (for example, pantomimes or emblems) are all similarly impacted by reduced visibility.

The effectiveness of the code also influences the division of labour between spoken language and gesture. For example, when communicating with a recipient who is a non-native speaker of the language, speakers expect the recipient to have difficulty de-coding speech and they produce representational gestures at a higher rate and more prominently[124,125]. When speakers use ambiguous words (for example, 'glasses,' which could refer to drinking glasses or spectacles), they use more representational gestures[126]. A gesture's decodability also influences its use. For example, in a task where the speaker identified a particular object in an array of multiple objects using speech and/or gesture, the speaker relied more on pointing gestures when the array was closer to the speaker than when it was further away. This pattern likely occurred because when the array is closer to the speaker, it is easier for the recipient to interpret which object the pointing gestures indicate[127].

Signers manipulate the imagistic (iconic) properties of signs to facilitate understanding. For example, sign language instructors often exaggerate or emphasize the iconicity of signs to aid learning in hearing students[128]. Similarly, child-directed signing emphasizes iconicity, which can help young children make the correct association between a sign's form and its meaning[129]. For example, caregivers are more likely to exaggerate the movement of the iconic British Sign Language sign DRIVE which depicts holding and moving a steering wheel, compared to the movement of the non-iconic sign PLAY, in which the movement bears little resemblance to playing[129].

The value of the message also influences how language and gesture are produced. For example, when it is especially important for the recipient to get the message, speakers produce representational gestures at a higher rate[130,131]. When the message contains new information for the recipient, the speaker produces representational gestures, which encode more information[132-134], at a higher rate[132,135,136], and more prominently, as compared to when the message is already known to the recpient[137,138]. Further, when the recipient appears to be attentive and value the speakers' message, speakers produce more representational gestures, as compared to when the recipient is not attentive[135]. In addition, when the recipient gives feedback to request more information, speakers produce gestures more prominently and informatively[134,139,140].

The need to communicate clearly also impacts how gesture and language are used by signers. For example, signers increase the use of co-sign gesture to enhance communicative efficiency[141,142]. Specifically, signers are more likely to depict actions using their faces and bodies (constructed action) when they have to communicate a greater number of simultaneous events, for example, describing a dog holding a bird while the bird pecks the dog's face, relative to simply describing a dog standing next to a bird. For the complex scene, a signer can depict the bird pecking their cheek with one hand (the signer's face represents the dog's face and the movement of their hand iconically depicts the bird pecking), while their other hand simultaneously depicts the dog holding the bird[142]. In this example, the gestural elements are the depiction of how the bird is held and where the pecking occurs. Thus, signers take advantage of co-sign gesture to efficiently express many simultaneous aspects of a complex scene[143].

The type of information also influences the division of labour between language and gesture. Gestures are especially suitable to convey spatio-motoric information[144]. Speakers produce representational gestures at a higher rate when talking about spatio-motoric contents than abstract contents[145,146], in particular when talking about manipulable objects than non-manipulable objects[147-150]. Similarly, as described above, co-sign gesture is suited to expressing deictic information (directing a sign toward a location in the environment) and depicting gradient, iconic information using the hands, face, or body (for example, to show the size of an object or the facial expression or body movements of a character).

Taken together, when gesture is judged to be useful for communication by the sender, gesture is produced more frequently, more prominently, and more informatively. Language users take advantage of different communicative affordances of language and gesture. They integrate the two systems to make communication effective and efficient.

[H2] Self-oriented cognitive functions

Representational gestures can also have a self-oriented function, shaping the producer's mental representation and cognitive processes. In particular, gesture that accompanies language production can activate, package and explore spatio-motoric representation[19].

Gestures can activate spatio-motoric representations such that producing co-speech gestures makes speakers think about, and therefore talk about, spatio-motoric contents. In tasks in which speakers can talk about any topic, they tend to talk more about spatio-motoric contents when they are allowed to gesture than when they are prohibited from gesturing[151]. Furthermore, in a task in which speakers think aloud to express how they are solving a problem that can be solved either by simulating movement of objects or by mathematics, people tend to use the simulation strategy more when they are allowed to use iconic gestures.[152] This finding suggests that iconic gestures support mental simulation by activating imaginary movement.

Co-sign gesture can also activate spatio-motoric representations, which can be used to facilitate memory. When signers are asked to recall a short list of signs in order, they often spontaneously produce signs at separate locations during recall, somewhat like the 'method of loci' that can be used to remember items on a list (for example, visualizing items at locations in a familiar environment, such as rooms in one's house). Importantly, signers remember lists of 'neutral space' signs—signs that allow deictic co-sign gesture—better than lists of body-anchored signs that do not have a moveable location[153]. Thus, the use of deictic co-sign gesture can help signers spatially encode the order of signs they need to remember.

Gestures can also help speakers package information into a unit suitable for verbalization[154]. When describing a motion event in which an object moves in a particular manner along a particular path, Dutch speakers could use either a single clause ('He rolled down the slope') or two clauses ('He went down the slope, as he rolled.'). When instructed to use either a single gesture to express both manner and path or two separate gestures for manner and path in a motion description task, Dutch speakers were more likely to use the single clause description in the single gesture condition than the separate gesture condition[154]. Thus, what information is packaged in gesture can influence how information is packaged in speech.

Furthermore, gesture can help people explore spatio-motoric information that is useful for language production and problem solving. In a creativity task, English speaking children were instructed to describe as many non-conventional uses for an everyday object (a newspaper) as possible. They came up with more possible uses when they were encouraged to gesture than when they were prohibited from gesturing[155]. Gesture enabled children to explore different ways of interacting with the object, which led to more ideas. Similarly, both deaf and hearing children produce 'language-gesture mismatches' when they are at the cusp of cognitive change[156]. When explaining their answers to a math equation on a blackboard, some children give one explanation in language (sign or speech) but give a different explanation in their pointing gestures. Such mismatches suggest that gestures reflect the exploration of ideas that differ from the linguistically expressed ideas. The children who produce language-gesture mismatches are more likely to benefit from instruction and successfully solve new equations than children who produce gestures that match their linguistic explanations[157,158]. Furthermore, when English speaking children were encouraged to gesture while explaining solutions to math equations, they generated new solution strategies that they had not expressed earlier without gesturing[159]. These findings suggest that children can use gestures to explore new ideas.

To summarise, the linguistic structure of the specific language used by signers or speakers impacts how representational gestures are produced. Gestures have communicative functions (increasing the clarity, effectiveness, and information content of the message) and self-oriented cognitive functions (activating, packaging, and exploring spatio-motoric mental representations). A given gesture can serve these two types of functions at the same time because effective communication requires clear conceptualisation of the message, and communicatively triggered gestures can shape thinking. Thus, gesture is produced at the interface of linguistic, communicative, and cognitive processes.

[H1] Gesture comprehension

Gesture production is modulated for communicative and cognitive needs. People on the receiving end of gestures take up information and integrate it with language information. Just as in studies on gesture production, studies on gesture comprehension focus largely on representational gesture, with some notable exceptions[81,160-162].

[H2] Information received

People glean information about all aspects of communication from gestures: the message, the physical context, the social context, the interactive context, and meta-gestural information (Table 3).

First, gesture can convey information contributing to the message: the information directly related to what the speaker or signer intends to get across to the recipient. The recipient can integrate information from language and co-speech gesture to derive the message. For example, a gesture enacting writing plus the sentence, ‘I paid’ is interpreted as paying by a cheque[163,164]. A gesture pointing to an open window plus a sentence, ‘I am getting cold’ is interpreted as a request to close the window[165]. The recipient more successfully gleans information from co-speech gesture when the message has motoric content than abstract content and when the gesture expresses additional information rather than information that is redundant with speech[144]. Further, co-speech gesture that adds extra information to speech can plant a false memory in the recipient[166-169]. Co-speech gesture expressing the meaning of novel words can help children learn the words[170-178]. Furthermore, if gestures associate multiple referents at multiple locations, a subsequent gesture at one of the locations can disambiguate an ambiguous expression in speech [179-181] (also true for deictic co-sign gesture that accompanies pronouns[182]).

Little research has been conducted on how co-sign gesture impacts comprehension of the signer’s message by recipients. One possible contribution of gesture is the meaning that is conventionally associated with locations in space[183]. For example, if a signer associates one referent with a high location in space and another referent with a low location, the recipient might interpret the referent at the higher location as more powerful or more authoritative, reflecting the conceptual metaphor ‘power is up’ in which powerful figures are placed above weaker individuals[184]. A referent associated with a location closer to the signer might be interpreted as reflecting the signer’s empathy for that referent, compared to a referent associated with more distant location. Indeed, American Sign Language recipients can make appropriate inferences regarding authority and empathy based solely on the locations associated with referents in signing space (K.E., unpublished data).

Second, gesture can highlight what is important in the physical communication context, thereby guiding the recipient’s attention to a particular location or entity. Deictic (pointing) gestures by speakers can draw the attention of the recipient to a particular location in the physical environment[138] or in the space in front of the speaker[179,180,185]. As noted above, environmentally-coupled co-sign gestures serve this function for sign languages because signs are directed toward entities in the environment[43].

Third, gesture can provide information about the social context, which includes characteristics of the language producer. For instance, when a speaker gives a speech to persuade the audience about a particular proposition, the audience judges the speaker to be more competent or a better information source when the speaker produces representational gestures than when they do not produce gestures[186-188]. When hearing a child explain a solution to a mathematical equation written on the blackboard, the teacher can glean the child's level of understanding based on how they coordinate speech and gesture, and accordingly change the strategy for instruction[189]. More specifically, when a child expressed two different solution strategies in speech and gesture, then the teachers were more likely to provide a broader range of strategies distributed across speech and gesture in the instruction. It is unknown whether teachers are sensitive to sign-gesture mismatches produced by deaf children or whether an audience considers a signer to be more competent or authoritative when they produce more co-sign gesture. However, the use of gesture in signing is associated with highly competent story-tellers and poets, suggesting that the use of co-sign gesture is associated with experienced and knowledgeable signers [190,191].

Fourth, gestures can provide cues to the interactional context, which is useful for coordinating conversational turns. When speakers produce a gesture in a question, there is a shorter conversational turn-taking gap between the question and an answer[192], and a shorter overlap between two speakers' utterances, as compared to when speakers did not produce a gesture[193]. Gestures can signal when the current turn might end[194,195] and foreshadow what information will be expressed in speech[14,196], providing cues used by the recipient for efficient turn-taking. Turn-taking in sign languages involves visual cues that can be either linguistic (such as question signs) or gestural (such as a palm-up questioning gesture or raised eyebrows), and both signers and non-signers can use gestural cues to predict conversational turn ends in signing [197]. In addition, eye gaze in signing is a powerful turn-taking regulator because it determines who has the floor[198]. Signers can signal their desire to maintain the floor by not looking directly at the addressee, and recipients can signal the desire for a turn by raising their hands from a rest position into signing space, which also allows them to precisely time their turn[199,200].

Fifth, the recipient can gather meta-gestural information from gestures. For example, the recipient can glean how useful gestures are as a source of information. In experiments in which participants integrate information from speech and gesture, they rely less on gestural information when there are many trials with uninformative hand movements (self-touches)[201] or with misleading gestures that mismatch the speech content[202]. No research to our knowledge has been conducted into whether meta-gestural information is associated with the use of co-sign gesture.

In sum, gesture can be quite beneficial for language comprehenders. They can use information conveyed by gesture to interpret the meaning of an utterance, to garner cues about the knowledge of the speaker or signer, to identify turn-taking opportunities, and to assess the reliability of the speaker's gestures (although this last usage has only been shown for spoken languages so far).

[H2] Integrating language and gesture

Communication recipients use all forms of relevant information, including gesture, to infer the sender's message as soon as the information becomes available. A few generalizations capture how recipients integrate information from language and gesture.

Recipients automatically integrate language and gesture[203]. This integration is automatic in the sense that when both types of information are available and participants make a judgement about spoken language (for example, judging if a spoken verb matches the preceding action video), semantically congruent information from gesture (for example, a co-speech action gesture) facilitates the judgement[179,203,204]. The same pattern is true in reverse: language influences gesture understanding. However, this integration is only automatic when the recipient can assume that speech and gesture are produced by the same person[204,205]. The degree of automaticity of integration of speech and gesture varies across individuals with different working memory capacities[206,207] (Box 2).

The location indicated by a gesture is also automatically integrated with the interpretation of spoken and signed language. Locations in space are often used for discourse cohesion: the same referent is placed in the same location[10,208,209]. Thus, recipients can interpret gesturally indicated locations as associated with these referents, across both co-sign and co-speech gesture [179,180,185,202,210-212].

Another generalization is that it is easier for recipients to integrate speech and gesture with each other when they overlap in time. Co-speech gestures often overlap with semantically related words in speech[10,196]. For instance, as the speaker says, ‘he threw the ball over the fence’, the speaker typically produces a gesture enacting the act of throwing simultaneously with the word, ‘threw’. When they do not overlap, gesture precedes semantically related words[213]. In event-related potential (ERP) studies in which participants were presented with a spoken word and an iconic gesture that either semantically matched or mismatched and at varying relative timings, semantic integration (as measured by the N400 potential) was strongest when the speech and gesture were overlapping, and the effect weakened when the gesture substantially preceded the word[214,215]. This result could be due to the fact that the meaning of iconic gestures is very vague without semantically related speech, and it is difficult to judge if a vague gestural meaning matches with speech or not[216]. However, iconic gestures that precede semantically related spoken words can be integrated when discourse context constrains their meaning[217]. No research has yet explored the timing of co-sign gestures or how they are integrated with language by recipients.

Finally, recipients focus more attention on gesture when speech is difficult to process. When recipients are presented with speech and gesture along with auditory noise that makes it hard to hear the speech, recipients allocate more attention to the gestures than when there is no noise[218]. Recipients also recognise speech that is accompanied by iconic gesture better than speech without gesture, especially when noise makes the speech difficult to hear [218-220]. This benefit occurs because recipients shift focus to gesture to glean information useful for speech recognition. This property might be specific to speech and gesture because they are comprehended across two perceptual channels (audition and vision), whereas both sign and co-sign gesture are perceived visually. That is, when the auditory channel is noisy or degraded, information conveyed by the visual channel garners more attention to aid comprehension. However, there has been no research on attention to co-sign gestures with a degraded visual signal.

To summarize, gesture conveys information to the recipient about the message the sender intends to convey, about the physical, social, and interactive context, and meta information about the communicative signal itself. The recipient readily integrates information from language and gesture to derive the sender's message, especially when the sender produces them with temporal overlap. Gesture plays an especially important role in communication when the message has spatio-motoric content and when communication using language is limited. Thus, recipients flexibly allocate their attention to speech and gesture to optimize information uptake and glean a broad range of information from gesture. They integrate the information from gesture and language to create a rich unified representation of the sender’s message.

[H1] Summary and future directions

Gesture is distinct from language in both spoken and signed languages. However, it is not fruitful to draw a sharp boundary between language and gesture. Together, both contribute to the rich expressive power of human communication, efficiently conveying information to recipients. Separately, they contribute to qualitatively different and complementary types of mental representations that together drive human thinking. Thus, to understand human communication and cognition, both gesture and language need to be considered.

Research on almost all aspects of co-sign gesture needs to be further developed. For example, little is known about how co-sign gesture might differ cross-linguistically or how recipients integrate co-sign gesture with language. Further, the self-oriented cognitive functions of co-sign gesture are understudied. It is unclear whether the use of co-sign gesture helps to activate and package spatio-motoric representations, similar to how co-speech gesture does. No studies to date have investigated possible individual variation in co-sign gesture production or comprehension, in contrast to what is known about individual variation for co-speech gesture (Box 2).

For both co-speech and co-sign gestures, the cognitive consequences of using gesture and language simultaneously need to be further explored. For instance, it is not clear if gesturing helps the language producer manipulate spatio-motoric representations in preparation for language production (‘thinking for speaking’)[221] [19]. As for co-speech gesture, previous research heavily focused on representational gesture, and more research on beat, emblem, and pragmatic gestures would be welcome. Such studies would clarify how gestures contribute to processing related to extended discourse and conversation.

Gesture production has been studied in more detail than gesture comprehension. One important question for gesture comprehension is how gesture is interpreted within discourse contexts. For example, it is not fully understood how the meaning of a gesture is constrained by information in the preceding and following linguistic and gestural context or the time course of this process for spoken and signed languages. Another important unanswered question is how the recipient integrates information from gesture and other visual cues such as communicatively relevant physical contexts (for example, the referent object). Furthermore, future research should explore whether spoken and signed languages differ in how language and gesture interact. Research filling these gaps will provide a more comprehensive understanding of human communication and thinking.

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Tables

Table 1. Distinctions between signs and representational gestures.

	Signs	*Representational Gestures*
Form-based Structure	Phonological structure	Holistic, no form-based internal structure
Grammar	Content signs (such as nouns and verbs) and grammatical markers (such as negation) combine into sentences	No grammatical function, combine only to depict multiple aspects of an event or object
Meaning	Typically opaque and context-independent	Typically transparent in context
Community Standards	Conventionalized	Few standards

Table 2. Interdependence between factors that distinguish gesture and language: level of conventionalization and transparency.

	Conventionalization	**Transparency**
Analytic thinking	High	Graded (Low to High)
Spatio-motoric thinking	Graded (Low to High)	Graded (Low to High)

Note: When conventionalization is low, transparency tends to be high, but when conventionalization is high, transparency varies.

Table 3. Types of information obtained from gestures

Type of information	**Description**	**Example**
Message	The information that the language producer intends to convey to the recipient.	Co-speech: 'I paid' produced with a writing gesture is interpreted as payment by cheque [Ref 161, 162] Co-sign: DANCE produced with body sway is interpreted as waltzing [Ref 29]
Important information in the physical context	The information that the language producer highlights in the physical context to draw the recipient's attention	Co-speech: Pointing gestures highlight the location in the environment being talked about [Ref 138] Co-sign: Environmentally-coupled signs directed toward objects in the environment highlight the link between the sign and the object [Ref 46]

Properties of the gesture producer	Cognitive and social characteristics of the gesture producer	Co-speech: speakers who produce representational gestures are considered to be more competent than those who do not [Ref 183-185] Co-sign: signers who make use of co-sign gesture are considered to be good story-tellers and poets [Ref 187-188]
Cues for coordinating interaction	The information useful for coordinating interaction, such as turn taking	Co-speech: Gestures can project when the speaker's turn may end [Ref 191-192] Co-sign: Eye-gaze during signing is a strong turn-taking regulator [Ref 95]
Meta-gestural information	Information about gesture, such as how useful gesture is as an information source.	Co-speech: Recipients rely less on gestural information when it is not informative (self touches) or not reliable (mismatched with speech) [Ref 198-199] Co-sign: Meta-gestural information has not been studied.

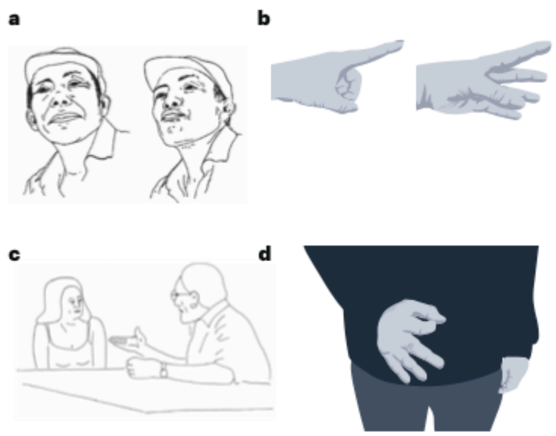
Figure legends

Figure 1. Deictic signs. In contrast to pointing gestures, different handshapes indicate the type of pronoun in many sign languages (for example, nominative, possessive, or reflexive). These examples are from American Sign Language.

Figure 2. Conventionalization in gestures. A) Example of pointing with lips in Panama[222]. B) Pointing handshapes with different meaning in the Arrernte people (Australia): an index finger is used to point toward a location or one entity, whereas the flat hand is used to point toward a region or multiple objects[64]. C) A palm-up flat hand gesture used in Naples (Italy) to acknowledge what the other person said is correct and to provide additional relevant information[8]. D) A Japanese emblem meaning 'money'.

Fig 1

Fig 2



Boxes

Box 1: Facts about sign language

Sign languages provide unique insight into the nature of human language and its cognitive underpinnings. To recognize this value, it is critical to debunk several common myths and misconceptions about sign language. The following properties characterize sign languages across the globe.

[H1] There is no universal sign language

No sign language is shared by deaf people around the world. The website Ethnologue currently lists 150 sign languages. New sign languages are still being discovered and documented. For example, Central Taurus Sign Language emerged within the last 50 years in an isolated region in Turkey[223]. Sign languages differ in their lexicon, grammatical rules, and historical relationships, in the same way that spoken languages do. The figure below shows the signs that mean ‘mother’ from four distinct sign languages: A) Deutsche Gebärdensprache (Germany), B) Nihon-Shuwa (Japan), C) Íslenskt táknmál (Iceland), and D) Türk İşaret Dili (Turkey).

[H1] Signs are not pantomimic gestures

Signs, like words and unlike pantomimic gestures, have an intricate compositional structure in which units of form (handshapes, locations, movements) are combined to create a sign. Signs are in turn combined in rule-governed ways to create sentences[224]. This complex hierarchical structure is not present in pantomime or in co-speech gestures. Further, the ability to pantomime and the ability to sign can be differentially impacted by brain injury, indicating that non-identical neural systems are involved[225,226].

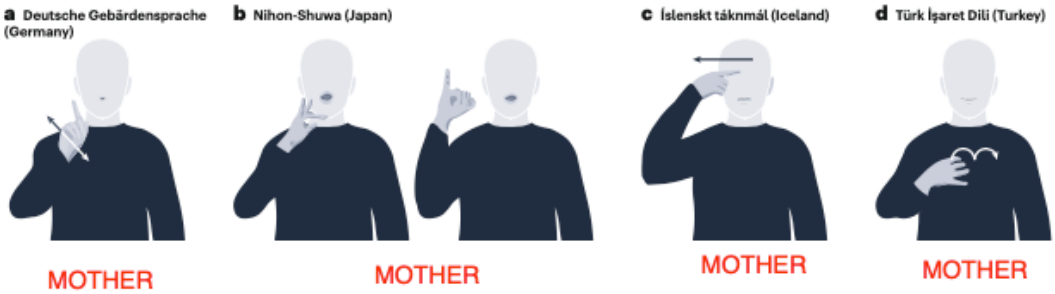
[H1] Sign languages are not based on spoken languages

A sign language is not a manual version of the spoken language used by the surrounding community, sign languages exhibit grammatical structures that are quite different from the proximal spoken language. For example, American Sign Language has a relatively free word order and marks time information on the verb (for example, whether an action is done regularly or for a long period of time) whereas English does not. Further, although American Sign Language and British Sign Language are both surrounded by the same spoken language (English), they are mutually unintelligible. In fact, there are no natural (non-invented) sign languages that are simply a transformation of a spoken language to the hands.

[H1] Sign languages can convey complex meanings

There is a misconception that there are ‘primitive’ languages or cultures, and this label is often applied to oppressed peoples, including deaf people[227]. The linguistic structure of all human languages, including sign languages, provides the same expressive power to convey philosophical and scientific concepts, as well as to create poetry[228].

Box 1


a Deutsche Gebärdensprache (Germany)
b Nihon-Shuwa (Japan)
c Íslenskt táknmál (Iceland)
d Türk İşaret Dili (Turkey)
MOTHER
MOTHER
MOTHER
MOTHER

Box 2. Individual differences

Multiple factors explain individual differences in co-speech gesture production and comprehension by adult language users[229]. The way people produce and comprehend gestures is related to their cognitive abilities, personality traits, and hemispheric lateralization for language. These relationships can inform how aging and neurological disorders influence the way people produce and comprehend gestures[229].

[H1] Gesture Production

Verbal and visuo-spatial abilities predict gesture production and cognitive consequences of gesturing. People with lower verbal and visuo-spatial abilities, as measured by linguistic fluency and working memory tasks, tend to produce representational gestures at a higher rate than people with higher abilities [230-232]. People who are visuo-spatial dominant (strong visuospatial ability but weak verbal ability) produce more representational gestures and their representational gestures tend to encode information not expressed in speech, as compared to people who are not visuo-spatial dominant [233,234]. Verbal ability also predicts self-oriented (cognitive) functions of gesture. Gesturing facilitates word retrieval, especially for those who have smaller verbal working memory capacity[235].

Personality traits also predict gesture production. People with higher empathy produce interactive gestures at a higher rate than people lower in empathy , and produce larger representational gestures [231]. People who are more extroverted produce more representational gestures than those who are less extroverted [236].

Finally, hemispheric language dominance also predicts gesture production and its cognitive consequences. Left-handed individuals vary in hemispheric dominance for language processing from left language dominance to roughly equal contribution from the two hemispheres. Left-handed individuals with left hemisphere language dominance produce gestures at a higher rate with the right hand than the left hand, but those with bi-lateral language produce gestures at comparable rates with the right and left hands[237]. Among right-handers when gesturing is prohibited for one of the hands, language processing contra-lateral to the prohibited hand is hampered[238].

[H1] Gesture Comprehension

There are fewer studies on gesture comprehension than production. People integrate information from speech and gesture more efficiently when they have a larger working memory capacity for reproducing a series of body postures[207] and larger visuo-spatial working memory capacity[206,239,240].