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Gesture in Spatial Cognition: Expressing, Communicating, and Thinking About Spatial Information

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Do hand gestures play a role in spatial cognition? This paper reviews literature addressing the roles of gestures in (1) expressing spatial information, (2) communicating about spatial information, and (3) thinking about spatial information. Speakers tend to produce gestures when they produce linguistic units that contain spatial information, and they gesture more when talking about spatial topics than when talking about abstract or verbal ones. Thus, gestures are commonly used to express spatial information. Speakers use gestures more in situations when those gestures could contribute to communication, suggesting that they intend those gestures to communicate. Further, gestures influence addressees' comprehension of the speech they accompany, and addressees also detect information that is conveyed uniquely in gestures. Thus, gestures contribute to effective communication of spatial information. Gestures also play multiple roles in thinking about spatial information. There is evidence that gestures activate lexical and spatial representations, promote a focus on spatial information, and facilitate the packaging of spatial information in speech. Finally, some of the observed variation across tasks in gesture production is associated with task differences in demands on spatial cognitive processes, and individual differences in gesture production are associated with individual differences in spatial and verbal abilities. In sum, gestures appear to play multiple roles in spatial cognition. Central challenges for future research include: (1) better specification of the mental representations that give rise to gestures, (2) deeper understanding of

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the mechanisms by which gestures play a role in spatial thinking, and (3) greater knowledge of the sources of task and individual differences in gesture production.

Keywords: Gestures, communication, spatial representations.

Introduction

I was once walking with a friend when a stranger stopped us to ask us directions. My friend was carrying two bags of groceries, one in each hand. He started to answer the stranger, but found it difficult to do so while holding the bags of groceries. After struggling for a few moments, he set the bags down so that he could move his hands as he gave the directions.

People often produce movements of the hands and body when engaged in effortful cognitive activity, such as speaking or solving problems. These movements are commonly called *gestures*. Many studies have documented that speakers produce gestures when they talk about spatial information, such as when giving directions (e.g., Allen, 2003), describing the layout of a room (e.g., Seyfeddinipur & Kita, 2001), describing an irregular shape (e.g., Graham & Argyle, 1975), or describing motion in space (e.g., Kita & Özyürek, 2003). Because gestures often accompany spatial language, it seems likely that they reflect spatial cognitive activity. Furthermore, given the difficulty some speakers have when they speak without gesturing, it seems possible that gestures may play a functional role in thinking or speaking about spatial information.

Is there a theoretical basis for the claim that gestures play a role in spatial cognitive activity? Indeed, many theories of gesture production hypothesize a role for spatial knowledge. For example, McNeill's (1992) seminal theory holds that gestures reflect mental images. According to McNeill, the core of the "idea unit" underlying any utterance (in his terms, the "growth point") contains both imagery and linguistic information. Idea units are expressed in gestures and speech together, with gestures expressing the imagistic aspect. This theory implies that spatial thinking is integral to gesture production, because mental images typically incorporate spatial information, and such images underlie gesture production.

Other theorists have argued that spatial mental representations give rise to gestures. For example, Kita and Özyürek (2003) argue that representational gestures originate from spatio-motoric representations, which contain spatial information and information about action. These representations serve as an "interface" between spatio-motoric thinking and speech production processes. According to this theory, gestures encode non-linguistic, spatial and motor properties of their referents, and they organize this information to be compatible with the possible options for expressing such information in language. Thus, spatio-motoric processes interact on-line with speech production processes, and gestures originate at this interface.

Krauss, Chen, and Gottesman (2000) also argue that representational gestures derive from spatial (or other non-propositional) representations of concepts. They developed a theoretical model, based on Levelt's (1989) model of speech production, specifying the processes involved in producing gestures. In their model, aspects of spatial representations are selected (by a "spatial-dynamic feature selector") and transformed into specifications for gestural movements. These specifications are then fed to a motor planner, and they ultimately dictate the way in which the gestures are executed.

Each of these theories of gesture production hypothesizes a role for spatial knowledge. Other theories that are not specifically focused on gesture also implicate body movements in complex cognitive activities, including spatial cognition. In particular, the embodied perspective on cognition holds that all cognitive activities are ultimately grounded in actions of the body (e.g., Barsalou, 1999; Glenberg, 1997; Glenberg & Kaschak, 2002). According to this view, overt bodily actions can contribute to and shape ongoing cognitive activity, so activities that are accompanied by actions may unfold in different ways than activities that do not involve actions. Because gestures are bodily movements, and because they often occur when speakers talk about spatial information, the embodied perspective suggests that gestures may affect speakers' thinking about spatial information.

Thus, there is ample theoretical reason to believe that gestures may play a role in spatial cognition. However, relatively little research within the field of spatial cognition has focused directly on gestures, despite the fact that spatial *language* is a common object of study. As Mark (1997) noted, "Many aspects of natural language can be used to get at principles of spatial reasoning and cognition. These include the grammar and syntax of languages, the lexicons of languages and their etymologies, as well as their semantics, pragmatics, and use." Noticeably absent from this list are the spontaneous gestures that routinely accompany language. In this paper, I argue that such gestures may also reveal principles of spatial reasoning and cognition.

The purpose of this paper is to review the literature on gestures, with an eye to the potential roles of gestures in spatial cognition. I focus on three spatial cognitive activities: (1) expressing spatial information, (2) communicating about spatial information, and (3) thinking about spatial information. Note that speakers may express spatial information in their gestures without this information being communicative in ordinary circumstances; therefore I distinguish between expressing spatial information on the part of a speaker (or gesturer), and communicating spatial information, which involves uptake on the part of an addressee.

For the purpose of the present review, gestures are defined as movements of the hands and arms that are produced when engaged in effortful cognitive activity (e.g., speaking, problem solving). Much of the gesture literature has focused on two broad classes of gestures. The first is *representational gestures*, defined as gestures that convey semantic content by virtue of the shape, placement or motion trajectory of the hands (e.g., tracing a triangle in the air to mean “triangle”, pointing to the right to mean “right”). This category includes gestures classified as *iconic*, *metaphoric*, and *deictic* by McNeill (1992), those termed *lexical movements* by Krauss and colleagues (Krauss, Chen, & Chawla, 1996), and those termed *illustrators* by Ekman and Friesen (1969). The second major category is *beat gestures*, defined as motorically simple, rhythmic gestures that do not depict semantic content related to speech. This category includes gestures termed *batons* by Ekman and Friesen (1969) and *motor movements* by Krauss and colleagues (Krauss et al., 1996). The existing literature on gestures in spatial cognition has focused on representational gestures because such gestures are adept at expressing spatial information. Throughout this paper, the term *gestures*, used on its own, should be taken to refer to representational gestures. When beat gestures or all types of gestures are intended, this will be noted explicitly.

The remainder of this paper is organized into five major sections. The first three sections review theory and empirical evidence regarding the role of spontaneous gestures in (1) expressing, (2) communicating, and (3) thinking about spatial information. The fourth section addresses variability in gesture production, both across tasks and across individuals, and considers whether such variation relates to spatial characteristics of the tasks or spatial abilities of the individuals. The final section highlights unanswered questions about gesture and spatial cognition, and points to important directions for future research.

The Role of Gestures in Expressing Spatial Information

Everyday experience suggests that speakers gesture at a high rate when expressing spatial information, such as when giving route directions or when describing the layout of a building. But are gestures really more frequent with language that expresses spatial information than with language that expresses other sorts of information? In this section, I review evidence that gestures are indeed associated with spatial language. I also discuss evidence that gestures reveal speakers’ viewpoints on the spatial information they express.

The information speakers express in gesture is accessible to experimenters who have the benefits of video and instant replay. Whether this information actually communicates to addressees in ordinary communicative situations is a separate issue, to be addressed in the following section. In this section, I focus exclusively on the speakers’ side of the communicative interactions.

Gestures Accompany Spatial Information in Speech

Representational gestures tend to occur with linguistic units that express spatial concepts. One way in which this association has been established is by comparing the frequency of gestures in naturally occurring utterances that express spatial concepts and those that do not. For example, Alibali, Heath and Myers (2001) asked participants to narrate a *Tweety and Sylvester* cartoon to a naïve addressee, and compared gesture rates in narrative units that contained spatial prepositions and units that did not. Speakers were nearly twice as likely to produce gestures with units that contained spatial prepositions than with units that did not contain spatial prepositions (59% vs. 32%). Similar findings were reported by Rauscher, Krauss and Chen (1996), using a different cartoon featuring *Road Runner vs. Wile E. Coyote*. Moreover, Rauscher et al. prohibited speakers from gesturing in one of their experimental conditions, and found that, for phrases that included spatial prepositions, speakers spoke more slowly when prohibited from gesturing than when allowed to gesture. Thus, gesture prohibition appears to make the expression of spatial information more challenging (as it did for my friend carrying the groceries).

Another way in which the association between gestures and spatial information has been established is by examining the content of linguistic units that do versus do not include gestures. Beattie and Shovelton (2002b) asked judges to evaluate the imageability of clauses that had been produced by speakers narrating cartoons, and compared the ratings assigned to clauses that included gestures and clauses that did not. *Imageability* was defined as “the ease or difficulty with which the speech unit arouses a mental image”; it seems likely that spatial information is highly imageable. Beattie and Shovelton found that speech units accompanied by gestures were rated as significantly more imageable than units that were not accompanied by gestures. This finding suggests that linguistic units accompanied by gestures tend to express spatial information.

Other studies have manipulated speaking topic and shown that that gesture frequency varies depending on speech content. For example, Lavergne and Kimura (1987) asked participants to speak for six minutes each on neutral topics (e.g., describe your typical school day routine), verbal topics (e.g., describe your favorite books and authors), and spatial topics (e.g., describe the route you would take to walk from the university’s main library to the main entrance of campus). Participants produced more than twice as many gestures when speaking about spatial topics than when speaking about verbal or neutral topics. In a similar study, Feyereisen and Havard (1999) compared gesture frequency in speakers who were asked to talk about motor information (e.g., explain how to wrap a box in paper for a present), visual information (e.g., describe the room in which you live most often), and abstract information (e.g., tell what you think about the use of a single currency in Europe). Speakers produced representational gestures most frequently in the motor condition, next most frequently in the visual condition, and relatively infrequently in the abstract condition; differences among all three conditions were significant. Furthermore, speakers produced beat gestures most frequently in the abstract condition. Thus, representational gestures tended to occur with visuo-spatial and motoric speech content; beat gestures, in contrast, tended to occur with more abstract speech content.

Finally, one study examined what aspects of a word’s meanings are associated with use of gestures. Zhang, as reported in Krauss (1998), investigated the amount of time that speakers gestured as they defined common English words that differed along several dimensions, including active versus passive, abstract versus concrete, and spatial versus non-spatial. Most of the variance in time spent gesturing was attributable to spatiality. Even with the other two factors partialled out, the correlation between spatiality and time spent gesturing was substantial ($r = .57$).

Thus, there is abundant evidence that speakers use gestures to express spatial information. However, the research to date has addressed this question at a fairly coarse level. Few studies have examined whether speakers are differentially likely to use gestures when expressing different types of spatial information, and few studies have examined the spatial information expressed in gesture in any detail. One exception is recent work by Trafton, Trickett, Stitzlein, Saner, Schunn, and Kirschenbaum (in press). They report that gestures are highly likely to occur (1) with speech that expresses *geometric relations*, which were identified by the presence of spatial prepositions (e.g., out, off, around), and (2) with speech that expresses *spatial transformations*, defined as cognitive operations performed on internal or external spatial representations (e.g., mental images, computer-generated images), such as mentally adding features to an image, rotating the image, and so forth. Moreover, Trafton and colleagues found that gestures are more strongly correlated with spatial transformations ($r = .52$) than with geometric relations ($r = .20$), which have been the focus of most previous studies of gesture and spatial language (e,g, Alibali et al., 2001; Rauscher et al., 1996). Thus, it appears that gestures may be better suited for expressing some types of spatial information than others.

Gestures Indicate Different Viewpoints on Spatial Information

One way in which gestures offer a unique window on spatial cognition is through revealing speakers' *viewpoints* on spatial information. McNeill (1992) was the first to distinguish different viewpoints in speakers' gestures. Specifically, he distinguished between *character viewpoint*, in which the speaker takes the point of view of the agent performing the action being described, and *observer viewpoint*, in which the speaker takes the point of view of an observer of the action. As one illustration, McNeill (1992) described a speaker recounting a scene in which a character in a comic book bent a tree to the ground. The speaker said, "he bends it way back" while producing a gesture in which his hand appeared to grip something and pull it down. In this case, the gesture reflects character viewpoint: the speaker is seeing the event from the viewpoint of the character bending the tree; therefore, his hand took on a grip handshape, as if his body were the character's body doing the gripping. An observer viewpoint gesture of the same scene might have depicted the tree itself bending back, perhaps using the forearm and hand to represent the shape of the tree itself.

McNeill's taxonomy of viewpoints was based largely on data drawn from speakers' retellings of stories that they had read or viewed (cartoons or movies). Researchers studying other types of content have also distinguished different viewpoints in gestures. For example, researchers studying spatial descriptions have identified *route* and *survey* perspectives in spatial language (Taylor &

Tversky, 1996) and corresponding viewpoints in gestures (Emmorey, Tversky, & Taylor, 2000). In route perspective, the viewpoint is within the scene, and the description provides an imaginary "mental tour" of the environment (as in "when you leave Memorial Union, turn right and walk down to the corner; you'll see College Library across Park Street to the right"). The corresponding gestures utilize *viewer space*, in which the gestures reflect an individual's view of the environment at a particular point in space and time (similar to character viewpoint). In survey perspective, the viewpoint is stationary and outside the environment being described, as in a bird's-eye view (as in, "College Library is just west of the Memorial Union"). The corresponding gestures utilize *diagrammatic space*, in which the gestures reflect a map-like model of the environment (similar to observer viewpoint).

Many factors influence speakers' use of viewpoint in gestures. For example, when producing narratives (such as recounting what happened in a cartoon story), speakers tend to express central events in the story line using character-viewpoint gestures, and peripheral events using observer-viewpoint gestures (Church, Baker, Bunnag, & Whitmore, 1989). Moreover, there are shifts in the ways that speakers use gesture viewpoint over developmental time. Children's earliest gestures tend to be mainly character viewpoint (McNeill, 1992), and the association of character-viewpoint gestures with central story events becomes stronger between ages 4 and 12 (Church et al., 1989). Findings such as these suggest that there may also be shifts in gesture viewpoint as a function of task or level of expertise, but this remains to be established.

Summary

There is extensive evidence that speakers use gestures to express spatial information. Gestures tend to accompany linguistic units that express spatial information (e.g., spatial prepositions, spatial transformations), and speakers gesture more when they talk about spatial topics than when they talk about abstract or verbal ones. Gestures not only coincide with spatial information; they also reveal speakers' viewpoint on that information. For example, gestures reveal whether a speaker conceptualizes a spatial environment from within or from above. Thus, gestures provide a unique and revealing window onto spatial cognitive processes. As Levinson (2003) eloquently stated,

> Unreflective gesture gives us insight into another level of mental life, representations of space that are at least partially independent of language, and that seem close to the very heart of our spatial thinking and spatial imagery. We can therefore look at gesture as a special window on underlying spatial cognition (p. 216).

The Role of Gesture in Communicating Spatial Information

Given that speakers use gestures to express spatial information, one obvious question is whether such gestures actually make a difference for addressees. Some investigators have questioned the communicative significance of gestures, arguing that gestures are instead produced in order to facilitate speech production (Krauss, 1998; Rauscher et al., 1996; Rimè & Shiaratura, 1991). These investigators have argued that any communicative effects of gestures are minimal, and at best epiphenomenal (Krauss, Morrel-Samuels, & Colasante, 1991). Despite these claims, however, there is abundant evidence that gestures play an important role in communication (see Kendon, 1994).

In this section, I review research addressing whether gestures contribute to communicating spatial information. With respect to this broad issue, two main questions arise. First, do speakers intend their gestures to be communicative? Second, do such gestures have communicative effects? Gestures might communicate, either by affecting the likelihood that speech is understood, or by directly conveying information that is not available in speech.

Speakers Intend Their Gestures to be Communicative

One source of evidence that speakers intend their gestures to be communicative comes from differences in gesture rates when addressees can see those gestures versus when they cannot. Indeed, speakers gesture more when their addressees can see them than when their addressees cannot see them. This phenomenon has been documented with several different tasks that involve communicating spatial information, including providing route directions (Cohen, 1977; Cohen & Harrison, 1973), recounting a cartoon story (Alibali & Don, 2001; Alibali et al., 2001) and directing another participant where to place pieces in a puzzle (Emmorey & Casey, 2001). Moreover, this effect is limited to representational gestures; beat gestures are not affected by manipulations of speaker visibility (Alibali et al., 2001). Thus, for representational gestures, at least, it seems to be the case that speakers *intend* their gestures to be communicative.

Some gestures are undoubtedly intended to communicate. Perhaps the clearest example is gestures that are explicitly referred to in the accompanying speech—as in “The fish was *this* [gesture] big!”. In such utterances, the information conveyed in gestures is not expressed at all in the accompanying speech, but it is clearly part of the speaker’s intended meaning. A few empirical studies have documented speakers’ use of gestures with deictic speech of this type. For example, Emmorey and Casey (2001) studied speakers directing addressees where to place puzzle pieces on a grid. When speakers could see their addressees, they sometimes used constructions in which speech made deictic reference to the accompanying gestures, as in “rotate it so that it’s *like this*” (p. 43). Such constructions accounted for 13% of instructions that included information about orientation of the puzzle pieces. In contrast, when speakers could not see their addressees, they never produced such constructions.

Along the same lines, Hegarty, Mayer, Kriz and Keehner (2005) describe a task that elicited many constructions that make deictic references to the accompanying gestures (which they refer to as *exophoric* descriptions). Participants were asked to talk aloud as they solved mechanical reasoning problems in which they needed to determine how one part of a mechanical system would move, if another part were moved in a particular way. They found that fully 71% of participants' descriptions of motions used verbal terms (such as "this way") that referred to the accompanying gesture. It seems clear that in such cases, speakers intend their gestures to complete the communication.

These findings suggest that speakers do intend their representational gestures to communicate, at least in some cases. However, evidence about speakers' intentions does not definitively address the question of whether gestures actually do contribute to communication. What is needed is evidence that gestures influence addressees' comprehension of speech, or that addressees take up information that is expressed uniquely in gestures. I turn next to studies that have sought such evidence.

Gestures Contribute to Effective Communication

It is well documented that addressees glean spatial information from gestures. Many studies of this issue have compared the effectiveness of communication under conditions with and without gestures. For example, Graham and Argyle (1975) asked participants (encoders) to describe a set of 24 line drawings to other participants (decoders), who in turn were asked to reproduce the pictures. The encoders described twelve pictures using gestures and twelve pictures without gestures. Further, twelve of the drawings were high in "codability", in the sense that they could easily be described in words, and the remaining twelve pictures were low in codability, in the sense that they were irregular and difficult to describe in words. The drawings produced by the decoders were then judged for similarity to the originals. Graham and Argyle found that the decoders' drawings were more similar to the originals when they were produced in response to descriptions that included gestures than when they were produced in response to descriptions that consisted only of speech. Further, this effect was stronger for pictures that were low in codability. Thus, speakers' gestures communicated information that facilitated decoders' picture drawings.

However, one problem with Graham and Argyle's study is that the content of speech was not well controlled. It is possible that speech content may have differed for pictures that were described with and without gestures. Indeed, a follow-up study with similar materials showed that prohibiting gestures led to an increase in the proportion of words used to denote spatial relations (Graham & Heywood, 1976). Thus, information that is normally expressed in gestures may be "translated" into speech when gestures are prohibited. Graham and Argyle's original findings, then, might be due to differences in the speech used to describe the pictures, rather than to any communicative effects of the gestures themselves.

More recent studies in which speech was better controlled have also shown that gestures contribute to communicating spatial information. McNeil, Alibali and Evans (2000) asked children to select blocks with particular features from an array of possible blocks, in response to videotaped directions that either did or did not include gestures (e.g., "Find the block that has a smile face with a rectangle below it…"). Children selected the correct block more often when the instructions included gestures that conveyed information that was redundant with (or matched) the information conveyed in the accompanying speech.

Many other studies have shown that redundant gestures facilitate comprehension of the accompanying speech (Glenberg & Robertson, 1999; Goldin-Meadow & Sandhofer, 1999; Thompson & Massaro, 1994). Furthermore, there is evidence that redundant gestures contribute more to comprehension when the verbal message is complex (Graham & Heywood, 1976; McNeil et al., 2000), ambiguous (Thompson & Massaro, 1994), or degraded in some way (Riseborough, 1981). Thus, the communicative importance of gestures depends, in part, on the quality of the accompanying speech.

These findings confirm that gestures can affect comprehension of the accompanying speech. But can gestures communicate information that is not conveyed in speech? Speakers sometimes express information in gestures that they do not express at all in the accompanying speech (McNeill, 1992); at issue is whether such information actually gets through to addressees. A personal anecdote suggests that such gestures do indeed communicate. In recounting a story about his childhood, my husband once said, "We had to go to a parade", while producing a gesture that mimicked waving a flag. Based on the gesture, I immediately inferred that he had been holding something, so I questioned him further. Indeed, he and his schoolmates had been given small flags to wave at the parade, which was held in honor of a visiting head of state. In this case, the spoken utterance did not mention anything about waving flags, or even about holding something; this information was only present in the gesture.

Goldin-Meadow, Alibali and colleagues have documented such mismatching or nonredundant gestures in their extensive work on children's explanations of their solutions to problem-solving tasks (Alibali, Kita, & Young, 2000; Church & Goldin-Meadow, 1986; Goldin-Meadow, Alibali, & Church, 1993; Perry, Church, & Goldin-Meadow, 1988). For example, in explaining her solution to a Piagetian liquid conservation task, a child might say, "This cup is taller," while indicating the width of the container in gesture. Mismatching gestures are especially frequent among children who are undergoing transitions in their knowledge of the concepts they are explaining (Alibali & Goldin-Meadow, 1993; Church & Goldin-Meadow, 1986; Perry et al., 1988). However, mismatching gestures are not limited to children or to problem-solving situations—they have been documented in adults explaining problem solutions (e.g., Garber & Goldin-Meadow, 2002), adults and children producing narratives (e.g., Barrett, 1998; McNeill, 1992), and adults tutoring children (e.g., Goldin-Meadow, Kim, & Singer, 1999).

Like redundant gestures, mismatching or nonredundant gestures influence addressees' comprehension of the speech they accompany. Several studies have shown that addressees comprehend speech less accurately when it is accompanied by mismatching gestures than when it is accompanied by no gestures or by matching gestures (Goldin-Meadow et al., 1999; Goldin-Meadow & Sandhofer, 1999; Kelly & Church, 1998; McNeil et al., 2000).

There is also evidence that addressees take up the information that is expressed uniquely in mismatching gestures, as I did in the parade flag example. In one study of this issue, Alibali, Flevares, and Goldin-Meadow (1997) asked teachers and college students to view video clips of children explaining mathematical equivalence problems (e.g., 3 + 4 + 5 = 3 + __). In some clips, children conveyed nonredundant information in gestures (e.g., pointed to addends that they did not mention in speech, or indicated the sides of the problem in gesture, without mentioning them in speech). Both teachers and college students often detected the information that children expressed uniquely in gestures. They sometimes reiterated that information in their own gestures, and sometimes translated it into speech. These data suggest that gestures communicate in and of themselves, and not only by affecting comprehension of the accompanying speech. Also, it is worth noting that, although the mathematical equivalence task that was the focus of this study is not primarily a spatial task, children's gestures often reflected spatial features of the problems (e.g., the two sides of the problems). Thus, it seems likely that the results would extend to gestures produced in other, more conventionally spatial tasks, although this remains to be established.

The evidence reviewed above makes a strong case that gestures contribute to communication. However, relatively little is known about the scope of the information that is communicated via gestures. To address this issue, Beattie and Shovelton (1999) presented participants with brief clips from narratives of a cartoon story. Some clips were presented in an audio-only mode, so that information was available only from speech, and some in an audio+video mode, so that information was available from both speech and gesture. The investigators then conducted structured interviews to determine exactly what information participants gleaned from the clips. The interview included seven questions that tapped 15 semantic categories, including questions about spatial properties of actions and objects (e.g., size and shape of objects, direction and speed of movement). All of the participants answered the questions more accurately with audio + video presentation than with audio presentation. Analyses of the individual semantic categories revealed that two semantic categories—object size and relative position—were communicated significantly more effectively in the audio + video condition than in the audio-only condition.

Summary

There is a compelling body of evidence that gestures contribute to effective communication of spatial information. Speakers use gestures more in situations when those gestures could contribute to communication; thus, they intend their gestures to communicate. More to the point, both redundant gestures and non-redundant gestures influence addressees' comprehension of the speech they accompany, and addressees also detect information that is conveyed uniquely in gestures. Thus, gestures play multiple roles in communicating spatial information.

The Role of Gesture in Thinking About Spatial Information

Although it is clear that gestures contribute to communication, many researchers believe that communication is not *raison d'etre* of gestures. Gestures also appear to play a self-oriented function for those who produce them, although there are differences of opinion about precisely what that function might be. Some possibilities that have been raised in the literature are (1) gestures facilitate access to items in the mental lexicon (e.g., Krauss, 1998), (2) gestures help speakers activate spatial information and maintain it in memory (e.g.. de Ruiter, 1998), (3) gestures highlight spatial information in reasoning and problem solving (e.g., Alibali, Spencer, & Kita, 2004), and (4) gestures help speakers to package spatial information into units appropriate for speaking (e.g., Kita, 2000).

The common thread across these accounts is that gestures are not simply an external manifestation of what is on the gesturer's mind. Instead, the act of gesturing influences the representations and processes that take place in the gesturer's mind. If this is the case, then producing gestures may actually influence the course of spatial reasoning and problem solving. Thus, a complete account of the processes involved in spatial reasoning will require understanding the potential contributions of gesture (and body movements more generally) to spatial cognitive activity.

In this section, I consider these four possible self-oriented functions of gesture and their implications for spatial cognition.

Gesture Facilitates Access to Spatial Terms in the Mental Lexicon

A number of investigators have proposed that gestures are involved in generating the surface forms of utterances, specifically, accessing items from the mental lexicon (Butterworth & Hadar, 1989; Krauss et al., 1996). The most detailed model of this process to date is that of Krauss, Chen and Gottesman (2000), which was described briefly at the outset of this paper. Krauss et al. argue that gestures derive from non-propositional representations of concepts, and in particular, gestures reflect spatio-dynamic features of concepts, which are features that involve spatial or action-based properties. For example, for the concept CUP, spatio-dynamic features might include the shape and size of the cup and the set of actions that could be performed with the cup (drinking from, tilting, etc.). When a gesture is produced, spatio-dynamic features of the concept are realized in the gesture, and "these features, represented in motoric form, facilitate retrieval of the word form by a process of cross-modal priming" (Krauss et al., 2000, p. 269). Essentially, according to this model, gestures express spatial and action-based properties of concepts, and the motoric expression of these properties feeds activation to other, related representations of the concepts, including lexical representations.

One core idea in this account is that the action of producing gestures feeds activation to certain types of mental representations. Other accounts of the self-oriented functions of gesture have also focused on the mental representations activated by gestures. I turn next to accounts that hold that gesture production increases activation on spatial representations rather than lexical ones.

Gestures Helps Speakers Activate Spatial Information and Maintain it in Memory

Several investigators have argued that gestures help speakers to activate mental images and to maintain them in memory. For example, De Ruiter (1998) asked speakers to describe arrays of shapes and lines to an addressee. For some speakers, the images were visible during the descriptions, and for other speakers, the images were removed from sight. Speakers produced more gestures when the images were no longer visible, suggesting that gestures helped them retrieve the images and maintain them in their mind's eye.

This general finding has since been replicated by two other research teams. Wesp and colleagues used still-life paintings as stimuli (Wesp, Hess, Keutmann, & Wheaton, 2001), and Morsella and Krauss (2004) used line drawings, some of which were highly codable (i.e., easily described in words) and others of which were less codable. In both studies, speakers produced more gestures when the images were no longer visible. Moreover, Morsella and Krauss found that this effect held for both high-codable and low-codable stimuli.

Taken together, these findings suggest that gestures help speakers to maintain mental images in working memory. But what mechanism might underlie this effect? A likely possibility is that the action of producing gestures feeds activation to mental images, so that they decay more slowly. By keeping mental images active, gestures may help speakers manage demands on spatial working memory.

Gesture Promotes a Focus on Spatial Information

If gestures activate spatial representations, then such representations should be more active when speakers produce gestures than when they do not produce gestures. As a consequence, speakers who produce gestures should focus more on spatial information than speakers who do not produce gestures, at least in situations in which they have a choice of what to talk about. In language production tasks, this should lead to differences in speech content when speakers gesture versus do not gesture. In problem-solving tasks, if problems can be solved using either spatial or non-spatial strategies, speakers who use gestures should be more likely to use spatial strategies than speakers who do not use gestures, because the spatial representations that support those strategies should be more highly activated. Several studies have yielded evidence in support of these predictions.

Rimè and colleagues examined the content of spontaneous conversations between an experimenter and a participant who was allowed to gesture during part of the conversation and prohibited from gesturing during part of the conversation (Rimè, Shiaratura, Hupet, & Ghysselinckx, 1984). Portions of the conversations were transcribed, and speech content was assessed using a "computer program of content analysis conceived to quantify the degree of speech imagery" (p. 317). Speakers received lower imagery scores when gesture was prohibited, and in particular, speakers spoke less about topics that involved action or movement. This finding suggests that producing gestures promotes a focus on spatial information (and relatedly, prohibiting gestures decreases focus on such information). However, because Rimè et al. provided little information about their content analysis program, this conclusion must remain tentative.

Alibali, Spencer, and Kita (2004) examined whether gestures influenced strategy use in a problem-solving task that could be solved using either spatial or non-spatial strategies. The task was gear movement prediction problems (originally studied by Schwartz & Black, 1996). In these problems, participants imagine an array of gears described by the experimenter, and determine how a particular gear would move if another gear were moved in a certain way (e.g., "Imagine 5 gears are arranged in a circle. If you try to turn the gear on top clockwise, what would the gear just to its left do?"). Participants who were allowed to gesture while solving the problems tended to use depictive strategies, in which they modeled the movement of each individual gear (usually in gestures) in an effort to infer the direction of movement of the target gear. In contrast, participants who were prohibited from gesturing often generated rule-based strategies (usually the *parity* rule, which holds that if there are an odd number of gears, the last gear goes the same direction as the first, and if an even number, the last gear goes in the opposite direction). Thus, gesture promoted reasoning based on spatial properties of the gears (direction of movement) rather than abstract rules. Producing gestures appeared to help solvers mentally represent the actions of the gears, and therefore promoted use of depictive strategies. When this support for mental representation of the gears' actions was not available, participants shifted to other strategies.[1]

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[1]Note that the parity strategy is more efficient than the depictive strategy, and it is based on a general principle that can be applied across problems. Thus, for the gear movement prediction problems, *prohibiting* gesture appears to encourage solvers to use a highly efficient and general, but non-spatial strategy, whereas *allowing* gesture appears to encourage solvers to use a less optimal, spatial strategy.

The crucial point here is that gestures promote reasoning based on *spatial properties* of the problem situation. However, whether spatial strategies are optimal or not depends on the specific problem situation. For gear problems, spatial strategies are non-optimal (though they are often successful); however, in other problem domains, spatial strategies may be superior to more abstract ones.

It seems likely that if gestures promote a focus on spatial information, then inferences relying on spatial information should be less accurate when gesture is prevented. This issue was addressed by Hegarty, Mayer, Kriz and Keehner (2005). Contrary to this hypothesis, they found that restricting gesture did not impair participants' performance on a set of mechanical reasoning problems that required drawing inferences about how one part of a mechanical system would move when another part was moved in a particular way. These findings are difficult to reconcile with the view that gesture activate spatial mental representations. However, in this regard, it is worth noting that in Alibali, Spencer, and Kita's (2004) study, there were also no differences in the number of problems participants solved correctly with and without gestures. Instead, gesture influenced the strategies participants used to arrive at their solutions.

In sum, several studies suggest that, when speakers have a choice of focusing on spatial information or non-spatial information in speaking and problem solving, gesture promotes a focus on spatial information. However, more work needs to be done to examine the scope of this effect, and to examine its implications for cognitive processes that involve spatial representations.

Gestures Help Speakers Package Spatial Information in Units for Speaking

Another possible self-oriented function of gesture is that gesture may help speakers to "package" spatial information into units suitable for verbal output. This view has been developed most fully by Kita (2000). The core idea is that speakers use gesture to explore possible ways of organizing information, and this exploration helps speakers find an effective way to express spatial information in the linear, segmented form of speech. Essentially, gestures help speakers to "find" chunks of spatial information that are suitable for verbalization.

One implication of this view is that situations that are more conceptually complex, in the sense that they allow more alternative ways of organizing information, should elicit more gestures. These situations presumably require (or at least allow for) more exploration as the linguistic output is being planned. To test this implication, Hostetter, Alibali and Kita (2005) (see also Hostetter & Alibali, 2004) asked participants to describe ambiguous dot patterns under two conditions. In the dots-plus-shapes condition, the dots were connected into geometric shapes, and the shapes provided a ready-made organization to assist participants in conceptualizing the dot patterns. In the dots-only condition, participants generated their own geometric conceptualizations in order to describe the dot patterns. As predicted, participants gestured more in the dots-only condition, when they had many options about how to organize the patterns, than in the dots-plus-shapes condition, when they had only a single option (the one given by the shapes). In a related study, Melinger and Kita (2001) found that in a route description task, adults were more likely to gesture when they had more choices about what to say. Taken together, these studies suggest that gestures are used to explore possible ways of organizing spatial information.

The literature also includes several examples in which gestures appear to help speakers conceptualize spatial situations in a manner suitable for verbal expression. Kita (2000) describes a speaker recounting a spatially complex scene from a cartoon. The speaker first produced an elaborate, highly complex gesture during a pause in speech; the gesture appears to reflect the speaker's spatial model of the scene as a whole. Following this, the speaker broke up the initial movement into a series of smaller gestures, each of which was ultimately verbalized in a linguistic unit. Kita interpreted this example as suggesting that gestures helped to chunk the spatial information into pieces small enough to be verbalized within one planning unit of speech.

Other relevant examples were presented by Emmorey and Casey (2001) in their study of speakers directing others where to place pieces in a puzzle. The pieces often needed to be rotated in order to be placed correctly, and speakers sometimes produced gestures depicting rotation during pauses in speech just prior to verbally describing the necessary rotation. One interpretation of these examples is that producing the gestures helped the speakers to package the spatially complex information about rotation in words.

Summary

There are many different accounts of the self-oriented functions of gestures, and how these functions are involved in spatial cognition. There is evidence that gestures activate lexical and spatial representations, promote a focus on spatial information, and facilitate the packaging of spatial information in speech. Fortunately, these accounts are not mutually exclusive. However, to get a handle on how these various functions work together in spatial cognition, we will need to better specify the cognitive processes that give rise to gesture production. A deeper understanding of these processes will allow more precise theorizing and more differentiated predictions about the nature and frequency of gesture in different tasks and different situations.

Sources of Variation in Gesture Production

There is enormous variation in gesture production across tasks and across individuals. Speakers gesture more in some tasks than others. Some speakers gesture almost continuously, whereas others gesture rarely or not at all. Might a consideration of spatial cognition shed some light on the sources of variation in gesture production?

Task Differences in Gesture Production

Two of the best-studied tasks in the literature on gesture production are narrative retell and direction giving. Not surprisingly, most participants gesture at a high rate in both of these tasks. Both of these tasks also involve spatial content, albeit of different sorts. Narrative retells tend to involve descriptions of actions, whereas route directions tend to involve descriptions of space. To my knowledge, no study has compared gesture rates in the same individuals providing narratives and giving route directions. Thus, at the present time, it is not known which type of task yields higher gesture rates.

Motor description tasks, such as describing how to wrap a package or how to tie a shoe, also elicit high rates of gesture (e.g., Feyereisen & Havard, 1999). Such tasks involve describing one's own potential or past actions, and as such, they presumably activate motor processes that could be involved in those actions. Hostetter and Alibali (2005) compared participants' gesture rates as they described how to wrap a package and as they retold what happened in a brief cartoon that they had just viewed. Participants gestured more than twice as often in the package task as in the narrative task (11.4 vs. 4.5 gestures per 100 words).

To elucidate task differences in gesture production, data are needed about how task characteristics relate to variations in gesture production. The research on this issue to date suggests that tasks that require access to mental representations of spatial and motor information elicit higher rates of gesture than tasks that involve abstract or verbal information (Feyereisen & Havard, 1999; Lavergne & Kimura, 1987). Further, tasks in which representations need to be held in mind elicit higher rates of gesture than tasks in which representations need not be held in mind (de Ruiter, 1998; Morsella & Krauss, 2004; Wesp et al., 2001). Finally, tasks in which speakers describe their own actions may elicit higher rates of gesture than tasks in which speakers describe actions that they have viewed (Hostetter & Alibali, 2005), although data on this point are scanty. Taken together, these findings point to the probable role of gesture in activating spatial and motoric representations. Tasks that require such representations tend to elicit a high rate of gestures.

Individual Differences in Gesture

Individual differences in gesture production are striking, yet they remain poorly understood. Given the research reviewed above, it seems promising to consider whether individual differences in gesture might relate to individual differences in spatial abilities, and in particular, individual differences in spatial ability or spatial working memory capacity. Surprisingly, however, little work has directly tested this relation. In the only study to my knowledge of this issue, Hostetter and Alibali (2005) found that gesture rate was highest among individuals who had a *combination* of high spatial skill and low verbal skill. It may be the case that when spatial skills outstrip verbal skills, people rely on gesture to communicate their spatial representations. Alternatively, speakers with strong spatial skills but weak verbal skills may rely on gesture to help them translate their spatial knowledge into verbal form.

A number of factors other than spatial and verbal skill also influence gesture production. Trafton and colleagues present evidence that speakers who have more expertise in a domain gesture more than speakers who have less expertise in the domain (Trafton et al., in press). Their sample included both expert and journeyman (novice) meteorologists and neuroscience (fMRI) researchers; no differences in gesture were observed as a function of domain. Trafton et al. used a logistic regression model to predict the occurrence of representational gestures on an utterance-by-utterance basis, as a function of expertise and other factors related to speech content. The analysis revealed that representational gestures were more likely to occur in utterances produced by experts than in utterances produced by journeymen. One possible explanation for this finding is that experts may have increased spatial ability within their domain of expertise, and this increased spatial ability may be associated with production of representational gestures. Alternatively, experts may conceptualize their domain of expertise differently from novices, and experts' conceptualizations may be more readily expressed in gestures. For example, experts may have a deeper understanding of how objects or phenomena within their domain of expertise relate to one another, and these relations may be manifested in gestures.

Another individual difference factor that appears to affect gesture production is task motivation. McNeil and Alibali (2001) examined gesture production in elementary school children's explanations of mathematics problems, as a function of their motivation for succeeding on the problems. Two types of motivation were assessed using questionnaires: motivation to learn and motivation to perform well. Note that motivation to learn implies a focus on the self (i.e., on one's own knowledge), whereas motivation to perform implies an emphasis on others (i.e., on others' evaluations of one's performance). Motivation to perform, but not motivation to learn, was related to variations in gesture production. More specifically, students with high performance motivation were more likely to gesture when explaining their problem solutions than were students with low performance motivation. Thus, individual differences in task motivation, and perhaps more broadly, differences in focus on the self versus others, may also be associated with individual differences in gestural behavior.

In addition to individual differences in gesture production, there may also be individual differences in reliance on gestures in communication. Beattie and Shovelton (1999) found that participants who were good at gleaning information from a video-only presentation also showed greater gains in information from an audio + video condition as compared to an audio-only condition. Thus, some participants appeared to be good at gleaning information from the visual channel, either alone or integrated with the audio channel. It seems possible that such individuals might rely on the gestural channel more than others do in ordinary communicative settings.

There may also be individual differences in reliance on gestures in thinking. To my knowledge, no research has addressed this possibility directly. However, it seems likely that individuals may differ in their need for the extra boost provided by gestures in thinking about spatial mental representations.

Summary

It seems likely that some of the observed variation in gesture production is due to task differences in demands on spatial cognitive processes, and some is due to individual differences in spatial abilities (perhaps in relation to verbal abilities).

However, other task and individual difference factors, such as domain expertise and motivation, also certainly account for some of the variation. Our understanding of sources of variation in gesture is surprisingly limited; future research on this issue is sorely needed.

Agenda for Future Research

This review has presented some of the abundant evidence on the roles of gestures in expressing, communicating, and thinking about spatial information. However, many questions about gesture and spatial cognition remain unanswered. In closing, I would like to highlight several important directions for future research.

One fundamental question that has stymied many investigators has to do with the nature of the mental representations that give rise to gestures. Given the strong links between gesture production and spatial language, it is tempting to conclude that gestures derive from spatial representations. However, one recent study has cast doubt on this conclusion. Wagner, Nusbaum and Goldin-Meadow (2004) asked participants to explain mathematics problems while performing either a verbal secondary task (remembering lists of letters) or a spatial secondary task (remembering the locations of dots on a grid). Participants were prohibited from gesturing during some of their problem explanations and they were free to gesture during other explanations. The investigators reasoned that if gestures derive from spatial representations, then producing gestures should lead to poorer performance on the spatial secondary task, because the two spatial representations would compete for the same limited resource. However, producing gestures should not impair performance on the verbal secondary task, because the two tasks draw on different resources (verbal vs. spatial working memory).

Instead, Wagner et al. found that speakers performed better on both the verbal and the spatial secondary tasks when they produced gestures during their problem explanations. They interpreted this finding as suggesting that the representations that underlie gesture production are primarily propositional rather than spatial. Wagner et al.'s findings are provocative, and they highlight the current dearth of knowledge about the precise mechanisms involved in gesture production. Of course, it is possible that different mental representations underlie different types of gestures, or that more than one type of mental representation could give rise to gestures. Furthermore, even if the mental representations that give rise to gestures are propositional, gestures could still function to activate spatial representations. Future work is needed to pin down the nature of the mental representations that underlie gestures.

Another fundamental issue has to do with the mechanisms by which gesture plays its role in communication. At present, little is known about how gesture and speech are integrated in real-time language processing. Likewise, little is known about the neural bases of gesture's contribution to communication, although some researchers have recently begun to tackle this issue (e.g., Kelly, Kravitz, & Hopkins, 2004). Finally little is known about how particular features of gestures influence their communicative power. Some preliminary work suggests that character-viewpoint gestures are more effective at communicating than are observer-viewpoint gestures (Beattie & Shovelton, 2002a). However, much more remains to be learned about how viewpoint, motion, use of space, timing relative to the co-expressive speech, and other salient features of gestures influence their communicative effectiveness.

Another challenge for future research is to understand the nature of gestures' roles in thinking. As described above, there are currently several competing views about the functional significance of gestures in speaking and thinking. It seems likely that each account holds a grain of truth. The real challenge will be to specify how these mechanisms work together in service of language production and problem solving.

A final challenge for future research is to elucidate the bases of individual and task differences, both in gesture production and in reliance on gestures in communication. A better understanding of the mechanisms involved in gesture production and comprehension will likely help to clarify the sources of these individual differences. In turn, a better understanding of individual differences may help constrain theories about the mechanisms involved in gesture production and comprehension as well as the functional significance of gestures. Tackling this issue from both directions would seem to be the most effective course of action.

In sum, spontaneous gestures appear to have many roles to play in spatial cognition. Gestures are a window onto the spatial cognitive processes that take place in speakers' minds, a means of communicating spatial information from one mind to another, and a tool that people use in service of spatial thinking and speaking. Given the multifaceted roles of gestures in spatial cognition, the importance of investigating the mechanisms that underlie gesture production and comprehension seems clear. A better understanding of gestures, their sources and their implications will enrich the study of human spatial cognition.

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