Effects of Gesture on Analogical Problem Solving: When the Hands Lead You Astray

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Abstract

We investigated the role of speech-accompanying gestures in analogical problem solving. Participants attempted to solve Duncker's (1945) *Radiation Problem* after reading and retelling a story that described an analogous solution in a different domain. Participants were instructed to gesture, instructed not to gesture, or given no instructions regarding gesture as they retold the story. Participants who were instructed to gesture as they retold the analogous story were more likely to mention perceptual details in their description and less likely to apply the analogous solution to the problem than participants who were instructed not to gesture. These results suggest that gestures can be detrimental to analogous problem solving when the perceptual elements of a story are irrelevant to its schematic similarity with a problem.

Keywords: gesture; analogical reasoning; problem solving

Introduction

Analogical problem solving involves using an analogous source, such as a military story about a general overtaking a fortress by dividing his troops, to solve a target problem, such as Duncker's (1945) Radiation problem in which rays are divided to bombard a tumor (e.g., Gick & Holyoak, 1980). One of the most difficult steps in analogical problem solving is noticing that there is a connection between the source story and target problem. Noticing the connection is particularly difficult when the source and the target are from different domains (e.g., a military story and a medical problem) and involve very different objects (e.g., armies and fortresses vs rays and tumors) (see Anolli, Antonietti, Crisafulli, & Cantola, 2001). In order to notice the connection despite such differences, problem solvers must schematitize the goals and relations between objects in each (Gentner & Smith, 2013). A military story can be applied more easily to a medical problem if both are being considered as instances where there are similar goals (e.g., overcoming a centrally located target) and possible means (e.g., dividing).

Such schema formation is more likely the less problem solvers focus on the objects involved in any particular source. Encountering multiple source stories, for example, increases the likelihood that a schema will be formed (Gick & Holyoak, 1983) as does seeing an informative diagram depicting the important features of the schema (Beveridge & Parkins, 1987; Chen, 1995). Moreover, pictures depicting a solution to a target problem are only helpful to problem solvers when they contain the same objects as those involved in the problem (Chen, 1995), perhaps because they cue participants that there is a similarity and encourage the formation of a schema that can apply to both target and source. In contrast, when the objects in the source are different from those in the target problem, focusing on those objects deters from noticing the connection with the target (Chen, 1995; Keane, 1987) and prevents participants from forming a schema that is applicable to both target and source.

While focusing on the objects in a source can be detrimental to problem success in a different domain, activating kinesthetic information that embodies the relevant schema (e.g., dividing, converging) can be beneficial. Catrambone, Craig, and Neressian (2006) found that acting out the military story with wooden blocks increased the likelihood of noticing the connection to the radiation problem. They argue that acting out the story with blocks encouraged the formation of a schema that included kinesthetic information about converging forces, and was therefore more general than a direct representation of the objects involved in the military story. Further, kinesthetic information can encourage schema formation even when there is no source story at all (Thomas & Lleras, 2007; 2009). Thomas and Lleras (2007) found that participants were more likely to solve the radiation problem when they produced eye movements in an unrelated task that mirrored the problem's solution (crossing in and out from the skin to the tumor many times, as multiple smaller rays would do) than when they produced unrelated eye movements.

It appears then that body movements can affect whether a problem solver forms a schema that can be applied to the radiation problem. In the present study, we explore the effects of a very specific kind of body movement in analogical problem solving – representational gestures. Representational gestures, hereafter simply gestures, are movements of the hand and body that coincide with speech. Gestures are actions, in that they involve the movement of the body; however, as has been argued by Goldin-Meadow and Beilock (2010), they are more than actions, too, because they represent ideas in a way that actions often do not. Gestures have been described as outward manifestations of mental representations that are deeply rooted in the sensorimotor system (Hostetter & Alibali, 2008). When speakers produce gestures, they are using their motor system to represent an idea that is already drawing on the perceptual system (Hostetter & Skirving, 2011). Thus, producing gestures is a natural consequence of the high involvement of the sensorimotor system in concept representation (e.g., Glenberg, 2010).

Further, there is increasing evidence that producing a gesture is not only epiphenomenal, but can actually strengthen underlying perceptual representations in the speaker's mind (e.g., Cook, Yip, & Godin-Meadow, 2010) and make it more likely that gesturers will focus on perceptual information as they solve problems. For example, children who gesture as they solve Piagetian conservation problems are more likely to describe perceptually present aspects of the stimuli (e.g., the height of the objects) than when they do not gesture (Alibali & Kita, 2010). In addition, Alibali, Spencer, Knox, and Kita (2011) found that adults who gestured while solving problems about gear movements were more likely to perseverate on perceptual and motor strategies than speakers who did not gesture.

Because gestures strengthen underlying perceptual representations in the speaker's mind, they have the potential to help or hurt schema formation, just as focusing on objects more generally can either help or hurt (Chen, 1995). When the objects being gestured about are relevant to a problem, gestures may strengthen problem solvers' focus on those objects, thereby making it more likely that they will notice a connection with the problem and form a schema that can be applied to both. On the other hand, when the objects being gestured about are irrelevant to a problem, strengthening the perceptual representations of those objects may make it harder for participants to look past the differences between the source and the target in order to form a schema that can be applied to both (i.e., a fortress and a tumor).

In support of this, Beilock and Goldin-Meadow (2010) found that participants who gestured about the weight of the discs during an explanation of their solution to the Tower of Hanoi had more trouble solving a new version of the problem when the disc weights had been changed than participants who did not gesture. Although the solution process is the same regardless of the weight of the discs involved, by gesturing about the disc weights, problem solvers strengthened the representation of weight in their mind, thereby making it more difficult to generate a schema about how to solve the Tower of Hanoi that was independent of this perceptual element. Similarly, Cooperrider and Goldin-Meadow (2014) found that speakers who gestured during an explanation of a source story were less likely to solve an analogous problem than those who did not gesture. However, they did not directly manipulate gesture in their study, making it difficult to know if the presence of gesture was a side effect of already rich perceptual representations or actually a causal mechanism that focused speakers' representations on perceptual elements.

In the present experiment, we examine whether gesturing about a source story affects the likelihood that a problem solver will notice the connection to a target problem in a different domain. If gestures are much like other kinds of actions, then they should encourage a representation of the source story that is schematic, thereby improving the likelihood of noticing the connection between the source and the problem. Much like the eye movements studied by Thomas and Lleras (2007) and the acting-on-blocks movements studied by Catrambone et al. (2006), producing speech accompanying gestures about the military story could encourage speakers to form a schematic representation of converging forces that in turn makes it easier to notice the similarity with a medical problem. On the other hand, if gestures are different from actions because of their tight connection to perceptual ideas (e.g., Goldin-Meadow & Beilock, 2010; Hostetter & Alibali, 2008), gesturing about the military story could encourage a representation that is less schematic and more focused on the specific objects present in the source story. Under this view, gesturing may make it less likely that speakers will schematitize the source story, and thus less likely that they will notice its similarity with the problem.

To examine these two competing hypotheses, we gave participants multiple attempts to solve Duncker's (1945) *Radiation problem*. In between attempts, participants read and retold an analagous military story, under the ruse of participating in an unrelated study. Participants were either instructed to gesture, instructed not to gesture, or given no instructions regarding gesture during their retells.

Method

Participants

The final sample consisted of 72 undergraduates (44 female) at two small colleges who volunteered to participate in exchange for extra credit. An additional 20 participants were not included because the participant solved the radiation problem during the pre-check (before having a chance to tell the story), the experimenter made a mistake in the protocol, or the camera was not positioned well enough to capture the participants' gestures during the retells.

Stimuli

The military story. The story, taken from Gick and Holyoak (1980), describes a general who raises an army to overtake a fortress located in the center of a town. The general learns that there are mines on all of the roads approaching the fortress. The mines will detonate if any large group of people crosses, but small groups of people can pass safely. The general splits his army into smaller groups that approach the fortress via different roads. The groups are not large enough to detonate the mines, but together, they are large enough to overtake the fortress when they converge in the center. Because speakers are more likely to gesture when they have seen an image of what they are describing (e.g., Hostetter & Skirving, 2011), the story was printed with a picture underneath the text of the fortress surrounded by roads.

The medical problem. Each participant was presented with Duncker's (1945) *radiation problem*. Briefly, the problem describes an inoperable tumor that can be destroyed with a certain kind of ray. However, at sufficient intensities to destroy the tumor, the ray will also destroy the healthy tissue around the tumor. Participants are asked to think of possible ways to destroy the tumor with the ray without affecting the healthy tissue. Although there are several possible solutions to the problem, we were only interested in the *convergence solution* that is suggested by the military story. Specifically, the ray can be split into several smaller rays that can pass safely through the healthy tissue, but still converge on the tumor with enough intensity to destroy it.

Procedure

Participants arrived individually and were told that the study was about the effects of taking breaks on problem solving. Participants first had 3 minutes to attempt to solve the medical problem as a pre-check to make sure that they did not already know the solution, either because others had told them about it or because they had encountered it in a course or in another study. Participants who generated the convergence solution during the pre-check were not included in the study.

Following the pre-check, those participants who had not generated the convergence solution were told that they would be given a break before attempting the problem again. During the break, they would be involved in another study about how people remember and communicate information. Participants were told that they would retell a story in their own words to a video camera. They then spent two minutes reading the military story.

Participants were then randomly assigned to one of three conditions. In the *Instructed Gesture* condition, participants were told to include hand gestures to depict important aspects of the story. In the *Restricted Gesture* condition, participants were told that, while they might be tempted to include hand gestures to depict important aspects of the story, they should not do so. The experimenter suggested that participants sit on their hands to remind themselves not to gesture. In the *No Instruction* condition, the experimenter did not mention gesture in the instructions and simply told participants to include important aspects of the story as they retold it. In all three conditions, the experimenter produced the same scripted hand gesture when delivering the instructions.

In all conditions, participants took as long as they wanted to retell the story. When they were finished, they were given another 3 minutes to generate solutions to the medical problem. The experimenter left the room during this time. Upon returning, the experimenter asked the participants to explain their solutions to the problem. If participants described the convergence solution, their experimental session was ended and they were debriefed.

If they did not describe the convergence solution, they were told that they would have one more opportunity to solve the problem after taking another short break, during which they would retell the military story a second time to the video camera. Participants were reminded of their gesture instructions before beginning. Participants were then given three more minutes to generate solutions to the medical problem. Although this procedure differs from the original protocol pioneered by Gick and Holyoak (1980), giving participants multiple opportunities to retell the story and work on the problem is similar to the procedure of other studies that have found an effect of movement on problem solving (e.g., Thomas & Lleras, 2009).

Results

All participants who were instructed to gesture as they retold the military story produced at least one representational gesture (n = 25). In addition, 20 of the 22 participants who were given no instructions regarding gesture spontaneously gestured as they retold the story, and 3 of the 25 participants who were told not to gesture produced at least one representational gesture despite having been asked not to. For all analyses reported here, the three individuals who did not follow the gesture restriction instructions have been excluded. We had hoped that more participants in the no instruction condition would spontaneously choose not to gesture, thereby allowing a comparison of those who gesture

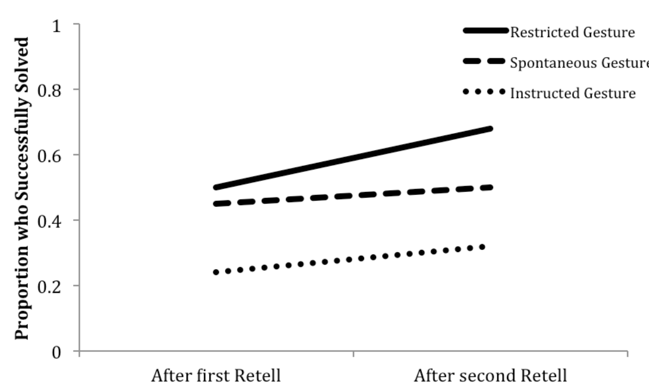

Figure 1. The proportion of participants in each condition who successfully generated the convergence solution to the Radiation problem after each retelling of the General story.

Table 1. Percentage of participants in each condition who mentioned each spatial element in their retelling of the story

Element	Gesture Instructed	Spontaneous Gesture	Gesture Restricted	χ^2
Fortress is centrally located	68	45	32	6.34*
Roads radiate outward	52	40	54	1.00
Army is large	52	15	27	7.36*
Army split into smaller groups	84	85	82	0.08
Groups come from different directions	68	70	32	8.29*
Groups meet in the middle	11	0	14	2.84

Note. * $p < .05$

spontaneously and those who do not. However, given that all but two participants in the no instruction condition gestured, such an analysis is not possible. We have therefore eliminated the two individuals who did not gesture in the no instruction condition from further analysis. Thus, the comparisons reported here are between participants who did not gesture after being instructed not to (n = 22), participants who gestured after being instructed to (n = 25), and participants who gestured spontaneously with no gesture instructions (n = 20).

Figure 1 shows the cumulative proportion of participants in each condition who generated the convergence solution to the medical problem following each retell. We analyzed the data in a mixed logistic regression model that included condition (*Instructed Gesture, Restricted Gesture, No Instruction*) as a fixed factor and college as a random intercept. Because gesture condition was manipulated between subjects and each participant only solved one problem, subject is not included as a random effect. We included a random intercept for college but not slope because the model failed to converge when slope was included.

For solution success after the first retell, there was no significant effect of condition, $\chi^2(2, N = 67) = 4.78, p = .09$. However, there was a significant effect of condition when considering success rate overall, $\chi^2(2, N = 67) = 6.75, p = .03$. Participants who were instructed not to gesture were twice as likely (68%) to generate the convergence solution to the medical problem by the end of the experiment than participants who were instructed to gesture (32%), $\beta = 1.64$, $SE = 0.65$, $z = -2.51$, $p = .01$. Participants who gestured spontaneously had a solution rate (50%) intermediate to and not significantly different from the other two groups.

Our hypothesis is that participants who gesture are less likely to solve the problem because of an increased focus on spatial and perceptual aspects of *The General Story*. To test this hypothesis, we coded each participant's retells for whether they mentioned six specific perceptual details regarding the spatial layout of the story (see Table 1). A one-way analysis of variance revealed significant differences in the total number of spatial details mentioned by participants during their retells across the three conditions, $F(2, 66) = 3.89, p = .025$. Participants who were instructed to gesture included significantly more spatial details in their retells than participants who were instructed not to gesture or participants who gestured spontaneously. As can be seen in Table 1, participants who were instructed to gesture were more likely than other participants to mention that the fortress was centrally located, that the army was large, and that the small armies approached the fortress from different roads. As predicted, instructing participants to gesture appears to increase the attention they pay to spatial details of the story as they are retelling it. Interestingly, however, participants who chose to gesture spontaneously, without specifically being told to gesture, did not focus on spatial details any more than participants who were told not to gesture.

Given that participants who were instructed to gesture were also the most likely to describe spatial details in their story, could their decline in success on the problem be due to their spatially rich descriptions, rather than to the gestures that accompanied them? In particular, two of the spatial details are analogous to the key transformations involved in the dispersion solution to *The Radiation Problem*: the army is split into multiple smaller armies and the smaller armies approach the fortress from different roads. To examine the possibility that it is mentioning these details, rather than gesturing about them per se, that affects problem success, we ran mixed logistic regression models predicting problem success based on whether each detail was mentioned. There was no effect for either detail (split: $\chi^2(1, N = 67) = 0.53, p = .47$; approach: $\chi^2(1, N = 67) = 0.06, p = .80$). It appears that mentioning these details is not predictive of problem success.

Finally, we more closely examined the gestures produced by participants to see if gesturing about particular concepts affected problem success. We coded the gestures produced by participants for whether they represented one of two concepts that are important to the dispersion solution: multiplicity and convergence. A gesture was coded as representing multiplicity when it indicated multiple places in space either by using two hands simultaneously or alternately or by using one hand sequentially to indicate three or more points in space. Such gestures typically occurred in the context of describing the multiple roads around the fortress or the many small army groups. A gesture was coded as representing convergence if it indicated moving towards the center from multiple radial locations, either by moving two hands inward simultaneously, by moving one hand from radial to center multiple times, or by drawing the fingers of one hand inward. These gestures occurred most often with speech about the armies moving towards the fortress along the different roads.

We considered whether each participant produced a gesture about multiplicity or about convergence in separate mixed logistic regression models. Although not significant by conventional standards, participants who gestured about the concept of multiplicity were less likely to solve the problem than participants who did not, $\chi^2(1, N = 67) = 3.68$, $p = .06$. Specifically, participants who gestured about multiplicity as a result of being told to gesture had worse performance than participants who were told not to gesture, $\chi^2(1, N = 47) = 4.92$, $p = .03$. In contrast, participants who gestured about multiplicity spontaneously did not differ from those who were told not to gesture, $\chi^2(1, N = 42) = 1.32$, $p = .25$. The same pattern emerged when convergence gestures were considered; participants who gestured about the concept of convergence were significantly less likely to solve the problem than participants who did not, $\chi^2(1, N = 67) = 4.32$, $p = .04$, but the effect is specific to individuals who were told to gesture compared to those who were told not to gesture, $\chi^2(1, N = 47) = 7.23$, $p = .007$. There is no difference in solution rate between those individuals who spontaneously gestured about convergence and those who were told not to gesture, $\chi^2(1, N = 42) = 0.72$, $p = .40$.

Discussion

Being instructed to gesture about the military story reduced the likelihood that participants would generate the convergence solution to the medical problem. We posit that this effect occurred because speakers who were told to gesture were particularly likely to focus on the objects involved in the military story, a focus that made it more difficult to form a schema that could also be applied to the medical problem. Indeed, speakers who were told to gesture were more likely to mention specific spatial details about the objects in their description than other participants.

The difference between spontaneously producing a gesture and producing a gesture after being instructed to do so is noteworthy. Previous research showing the effects of gesture on problem solving has not specifically compared the effects of gestures that were instructed with those that were spontaneous, though in many of these studies, participants were specifically instructed to use their hands during the explanation task (e.g., Beilock & Goldin-Meadow, 2010). It appears that, at least in the case of analogical problem solving studied here, being instructed to gesture produces or exaggerates the effect. There are several reasons why this could occur.

First, being told to gesture likely makes participants more consciously aware of their gestures. Having the conscious intention to produce a gesture could strengthen the underlying mental simulation that gives rise to gesture (e.g., Hostetter & Alibali, 2008). As a result, speakers who intentionally gesture may have richer mental representations that are more strongly grounded in perceptual and motor simulations than speakers who avoid gesturing or who gesture without thinking about it. Alternatively, there may be differences in the cognitive effects after the gesture is produced. Goldin-Meadow and Beilock (2010) argue that gestures bring perceptual information to the forefront of speakers' thinking; this may only occur when speakers are consciously aware of their gestures, as when they have specifically been told to produce them.

Regardless of why being told to gesture hurts, the present results suggest that speech-accompanying gestures do not have the same effect on problem solving as the movements studied by Thomas and Lleras (2007, 2009) or the actions studied by Catrambone et al. (2006). Specifically, Thomas and Lleras found that eye movements, movements that did not represent any particular concept, aided problem solving in their studies. However, speech-accompanying gestures are different from these movements because gestures are meaningful to the speaker; in order to be produced, they must represent something. When a speaker produces a gesture about the concept of multiple roads radiating outward from the fortress, the gesture corresponds to the specific mental image the speaker has in mind. Thus, as Goldin-Meadow and Beilock (2010) argue, gestures are a special kind of action. By virtue of representing images, gestures act to strengthen those images in the speaker's mind, and can make it more difficult to form a general schema that transcends the objects represented in those particular images.

Our results are also different from the findings of Catrambone et al. (2006), who found that acting out the military story using blocks aided analogical problem solving over simply retelling the story. In contrast, acting out the story using gestures in the present study impaired analogical problem solving. There are of course many methodological differences between the two studies that could account for the difference in findings, but there may also be a meaningful difference between the gestures studied here and the block movements studied by Catrambone et al. Using blocks to act out the story requires that the storytellers think abstractly about how the story elements can be represented with blocks, which may encourage thinking schematically about the relational elements of the story rather than the objects. In contrast, producing gestures about the story elements may not require the storyteller to engage in an abstract mapping between story and hand because gestures are used so ubiquitously and automatically to express meaning (e.g., Hostetter & Alibali, 2008).

Finally, it is possible that rather than gestures being detrimental to problem success, the act of not gesturing was beneficial. That is, perhaps being told not to gesture freed up cognitive resources that could then be used to think schematically about the story (e.g., Waltz, Lau, Grewal, & Holyoak, 2000). It is difficult for us to rule this possibility out definitively. However, we find the explanation untenable for two reasons. First, when given no instructions regarding gesture, most participants spontaneously produced them, suggesting that gesturing while retelling the story was natural. Thus, refraining from gesturing was likely more difficult than gesturing. Second, previous research has shown that producing gestures reduces cognitive load in other tasks (e.g., Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001). Thus, there is no evidence to support the idea that gesture production utilizes more resources than speech alone. Rather than utilizing cognitive resources, we argue that producing gestures focused speakers' attention on the concrete perceptual and motor elements of the story, thereby reducing their likelihood of forming an abstract schema that could be applied to the problem.

This explanation suggests several possible avenues for future research. First, whether gestures about the source help or hurt should depend on the similarity of objects and perceptual features between the source and target. Focusing on the objects involved in the source is not always detrimental; when there are similar objects involved in the source and target, thinking about the objects can actually help problem solvers notice the connection (e.g., Chen, 1995). Thus, gesturing about a source story that involves rays might actually improve the likelihood of noticing the connection with a target problem that is also about rays. We are currently testing this prediction.

Second, the participants in the present study read only a single source story. Previous research has shown that being exposed to multiple source stories increases the chances that problem solvers form a schema that can be applied more generally to a problem (e.g., Gick & Holyoak, 1983). Perhaps if problem solvers gestured about multiple source stories, they would notice the similarity in their gestures across stories and be more likely to form the abstract schema of converging forces. Cooperrider and Goldin-Meadow (2014) tested this prediction, but found no evidence to support it. In fact, they found that speakers who gestured about multiple source stories were less likely to generate the convergence solution than speakers who did not gesture, paralleling the effect we found here.

In conclusion, gestures have been shown to play a role in solving problems of various types (e.g., Alibali et al., 2011; Beilock & Goldin-Meadow, 2010). We have extended this work to examine the role of gesture in analogical problem solving and provided evidence that gestures make it *more difficult* to notice a similarity between a source and target that are in different domains. These findings suggest that when it is more important to focus on schematic relationships rather than perceptual properties, problem solvers may be best off keeping their hands still. For example, in a Physics problem involving physical forces on particular objects, gesturing about the objects in the problem may focus participants' attention on those particular objects, rather than on the more general forces at work that are essential to understanding how to solve the problem.

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