The Role of Gesture in Analogical Problem Solving

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Abstract

We hypothesized that gestures, which are often schematic in form, might play a role in making ideas more schematic and thus more transferable to new contexts. Adapting Gick & Holyoak's (1983) analogical reasoning paradigm, we had participants read and retell two stories, one after the other, and then try to describe their similarities. The stories share a helpful strategy for solving a problem that participants would encounter later. Contrary to predictions, participants who spontaneously gestured about the helpful strategy during the retelling phase did not solve the problem as frequently as those who kept their hands still. But participants who spontaneously gestured about the strategy when *comparing* the stories during the similarities phase were not hindered in the same way. Our results suggest that gesture may have contrasting effects at different stages of analogical reasoning, perhaps through a common mechanism of maintaining and entrenching representations.

Keywords: analogy; gesture; schematization; problem solving

Introduction

When faced with a novel problem, a fruitful strategy is to mine one's past experience for similar problems and then arrive at a solution to the new problem by analogy with an old one. Helpful analogies may be easy to spot from afar or after the fact, but in the rush of real-world problem solving they often elude us. What leads people to find helpful analogies in some cases but fail to do so in others? Previous work has demonstrated that one important predictor of whether an idea will be transferred to a new context is the nature of the idea (Gick & Holyoak, 1983). Ideas that are grounded in the concrete particulars of specific cases are unlikely to transfer, whereas ideas that abstract away from those particulars— that is, *schematic* ideas— are good candidates for transfer. This finding led Gick & Holyoak (1983) to predict that "any manipulation that can facilitate schema formation will boost analogical transfer" (pg. 25). A key question then becomes: are there ways to foster the schematization of ideas and, in turn, foster analogical reasoning?

Here we explore the possibility that a ubiquitous behavior— the gestures we cannot help but produce as we talk— might foster this kind of schematization. No matter the context or content domain, people will gesture spontaneously when they are wrestling with and describing ideas. Could this hand-waving matter? Recent work suggests that the answer is yes. Gesturing leads learners to express ideas they would not have otherwise expressed (Broaders et al., 2007); it can make learning last longer (Cook et al., 2010); and it can provide a vehicle for learning entirely new ideas (Goldin-Meadow et al., 2009). One clue to how gestures may exert these powerful effects on thought may be found in the forms they take. Gestures are often highly schematic, only exhibiting the barest essence of whatever idea or image they help express. For example, in describing a complex visual scene, a speaker may produce gestures that depict basic spatial forms and relationships within the scene. Arnheim (1969) suggested that this schematic nature of gesture is central to its usefulness. He writes: "The portrayal of an object by a gesture rarely involves more than one isolated quality or dimension... [I]t is useful not in spite of its spareness but because of it... The gesture limits itself intelligently to what matters" (pg. 117). If Arnheim is correct that gesture "limits itself intelligently to what matters," gesturing might play a role in making ideas more schematic and thus more transferable across contexts.

To investigate this possibility, we introduced gesture into a paradigm developed by Gick & Holyoak (1983). In addition to being a well-studied model system for understanding analogical problem solving, Gick & Holyoak's paradigm features a fundamentally *spatial* analogy, which should lend itself to expression in gesture (Alibali, 2005). In our version of the paradigm (adapted from experiment 4 of Gick & Holyoak [1983]), participants first complete a "story phase" in which they read and retell two stories, one about a military strike and another about dousing a fire that is raging out of control. Next, in the "similarities phase," participants describe any similarities they noticed between the stories. In addition to a number of superficial similarities, the stories share at their core an abstract solution to a problem: they both involve the redistribution of a force around a central target and the subsequent deployment of the force from all angles. Finally, under the guise of a separate study, participants attempt Duncker's (1945) "radiation problem," which can be solved by applying the redistribution strategy[1] suggested by the

[1] Previous reports have emphasized "convergence" as the central feature shared by both of the stories and the analogous solution to the radiation problem. However, we have found that mentions of

stories. The paradigm allows us to ask how gestures produced at two distinct time-points— first, when consolidating a helpful idea in the "story phase" and, second, when attempting to articulate that helpful idea in more abstract form in the "similarities phase"— might lead to analogical transfer. We predicted that, at both phases, producing gestures representing the redistribution strategy would lead people to later propose an analogous solution to the radiation problem. We also predicted that qualitative features of the gestures produced might matter. For example, if participants produce similar redistribution gestures across both stories, this might lead them to recognize the schematic core that the stories share and as a result be more likely to transfer this idea to the radiation problem.

Methods

Participants

94 adults from the University of Chicago community participated in exchange for payment or course credit. 7 participants were excluded because of prior knowledge of the radiation problem, 4 were excluded because they had technical knowledge of radiation techniques used in medical treatment, and 5 were excluded because of experimenter error. Data from the 78 remaining participants (49 women, 29 men; mean age of 21.7 years old) were analyzed.

Materials

All materials for were taken from Gick & Holyoak (1983). These materials included the two stories, 'The General' and 'The Fire Chief,' used in the story phase as well as the text describing Duncker's radiation problem.

Procedure

After consenting to participate, participants were told they were first going to participate in a study about how people remember and retell stories. They were then given one of the two stories ('The General' or 'The Fire Chief,' order counterbalanced across subjects) and asked to read it carefully so that they would be able to retell it later on. After three minutes, the story was taken away and a confederate, posing as another participant, was brought in. The participant was asked to retell the story they read to the confederate. No mention of gesture was made. When they were done, the confederate left the room and the participant was handed the second story. After three minutes, the confederate was brought in again and the participant retold the second story. These two retellings together constitute the "story phase" of the procedure.

Immediately after the second retelling was complete, with the confederate still present, the participant was asked to take a moment to consider any similarities between the two stories and then to describe them. Both the story and similarities phase were video-recorded for later analysis of participants' speech and gesture.

After the similarities phase was complete, the confederate was dismissed and participants were told that they were next going to participate in a study on problem solving. They were presented with Duncker's radiation problem and were given eight minutes to both read the problem and write down plausible solutions to it. When the allotted time was up, participants completed several questionnaires and, finally, were asked about any prior knowledge they may have had of the radiation problem.

Analysis

We analyzed participants' speech and gesture in both the story and similarities phases using ELAN annotation software. Participants' retellings in the story phase were annotated for whether or not they mentioned the redistribution strategy. At a critical point in both stories, a force (troops in the case of the General story, water in the case Fire Chief story) is re-organized so that it surrounds a central target (the fortress, the fire). Whenever they occurred in the participants' retellings, mentions of this critical change in strategy were classified as present in *speech only*, *speech and gesture*, or *gesture only*. Redistribution was considered present in gesture if the gesture *iconically* represented the redistribution of force— for example, by representing the division of the army into small groups in the case of the General story or the decision to surround the fire in the case of the Fire Chief story (see Figure 1). Such gestures were also annotated for the overall shape that they represented, such as whether the circle was represented as a continuous arc or a series of discrete positions.

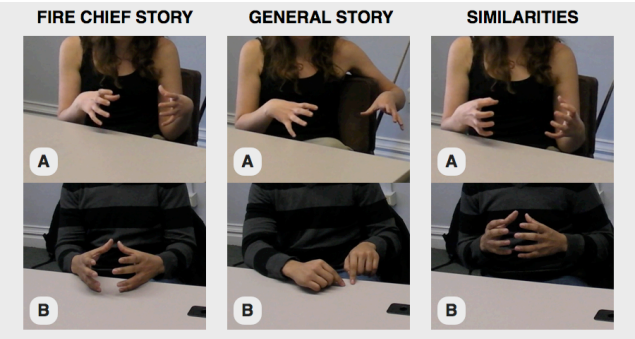

Figure 1: Examples of redistribution gestures produced by two participants over the course of the procedure. In the Fire Chief story, gestures produced along with mentions of redistribution often represented a circle surrounding the fire (A and B). In the General story, gestures produced along with mentions of redistribution often represented the divided army (A) or traced the army's new formation around the fortress (B). In the similarities phase, generic redistribution gestures often echoed these concepts of division (A) or surrounding (B).

the convergence of forces may be less important for predicting solution success than mentions of the initial insight to create a new spatial distribution of the force. Our discussion throughout thus focuses on the moment of initial *redistribution*.

Table 1: Solution success on the radiation problem as a function of mentions of redistribution in speech and/ or gesture in the story phase.

Gesture	*Speech in both stories*	*Speech in one story*	*Speech in neither story*	**Total**
Gesture in both	.38 (15/39)	--	--	**.38 (15/39)**
Gesture in one	.50 (7/14)	.30 (3/10)	--	**.42 (10/24)**
No gesture in either	.89 (8/9)	.67 (2/3)	.00 (0/3)	**.67 (10/15)**
Total	**.48 (30/62)**	**.38 (5/13)**	**.00 (0/3)**	

Participants' descriptions in the similarities phase were annotated in a similar fashion for whether or not they mentioned redistribution. Mentions of redistribution in the similarities phase came in two forms. Of particular interest were *generic mentions*, in which the participant explicitly mentioned redistribution as a feature common to both stories. Generic mentions of redistribution in speech might include statements that both stories involved "splitting up," "dividing," or "spreading things out." Occasionally, participants used phrasing that was not inherently spatial— e.g. "both stories involved organization"— while producing an iconic spatial gesture clearly depicting redistribution. These were considered gesture-only mentions of redistribution. Participants also produced *story-specific mentions* of redistribution, in which the participant merely mentioned that redistribution occurred in one story, without explicitly noting that this was in fact a feature common to both stories. For example, in order to support the statement that "both stories involved a strong leader," a participant might describe how the general ordered his troops to break up into small groups. Gestures in the similarities phase were coded in the same way as gestures in the story phase, and in the same way regardless of whether they occurred in the context of generic or story-specific mentions of redistribution.

Finally, each participant's proposed solutions to the radiation problem were analyzed for the presence of the desired analogous solution. In order to be scored as having the solution present, participants had to propose a radiation treatment in which, instead of deploying the radiation from one direction, multiple low-intensity rays were arranged so as to converge on the tumor from different angles.

Results

Overall solution success

Out of the 78 participants, 35 (.45) successfully produced the analogous solution to the radiation problem. This solution rate is close to the proportion of .52 reported for the most comparable condition of experiment 4 reported in Gick & Holyoak (1983). An unanticipated finding from our study was that solution success was related to the order in which participants received the stories: only 12/38 (.32) of participants who started with the Fire Chief story solved the radiation problem, compared to 23/40 (.58) who started with the General story ($\chi 2$= 4.3, 1 df, n= 78, p= .04, Cramer's V= .26).

Story Phase

We next analyzed whether participants' spoken mentions of redistribution in the story phase predicted whether they would go on to solve the problem (see Table 1). 62 participants mentioned redistribution in speech both in their retelling of the Fire Chief story and in their retelling of the General story (30/62 [.48] succeeded on the radiation problem); 13 participants mentioned redistribution in their retelling of only one of the stories (5/13 [.38] succeeded on the radiation problem); and 3 participants did not mention redistribution in their retelling of either story (0/3 [.00] succeeded on the radiation problem). This pattern, while perhaps suggestive, did not reach significance.

A more interesting pattern emerges when these spoken mentions are broken down into those that also involved gesture and those that did not[2]. Considering first the 62 participants who mentioned redistribution in both stories: 39 accompanied their spoken mentions with gesture in both cases and 15/39 (.38) went on to solve the problem; 14 accompanied their spoken mentions with gesture for one story but not for the other and 7/14 (.50) went on to solve the problem; 9 only mentioned redistribution in speech, never accompanying their mentions with a gesture, and 8/9 (.89) went on to solve the problem. For these 62 participants, presence of gesture when mentioning

[2] Gesture-only mentions of redistribution were rare in the story phase and are not included in the analysis. They were more common in the similarities phase and are therefore included in our analysis of it.

Table 2: Solution success on the radiation problem as a function of mentions of redistribution in the similarities phase.

Generic mention (all but 2 involved gesture)	.68 (15/22)
Story-specific mention only (all but 1 involved gesture)	.36 (8/22)
No mention	.35 (12/34)
Total	**.45 (35/78)**

redistribution was thus not independent of solution success (two-tailed Fisher's exact, p= .02). Considering next the 13 participants who mentioned redistribution in only one of their retellings: 10 accompanied their spoken mentions with gesture and 3/10 (.30) would go on to solve the problem; 3 mentioned it only in speech and 2/3 (.67) went on to solve the problem. These proportions, while not statistically different from each other, echo the pattern found for participants mentioning redistribution in both stories.

We next examined the form that these redistribution gestures took. Gestures about redistribution in the Fire Chief story invariably involved tracing or modeling a circle with one or both hands (see Figure 1). Gestures about redistribution in the General Story either represented the division of the army into multiple units, or else showed the reorganization armies into a circular formation surrounding the fortress. Some participants thus produced gestures that shared the same gestalt— by representing a circular formation in the General story and a circular formation in the Fire Chief story— while other participants produced gestures with contrasting gestalts— by representing a divided formation in the General story and a circular formation in the Fire Chief story. This serendipitous variation allowed us to explore whether producing two gestures representing the same spatial gestalt might make people more likely to discover the idea of redistribution at their core and then use this idea to solve the radiation problem. Of the 39 participants who produced redistribution gestures in both of the stories, 9 people produced gestures in the stories that both represented the *same* spatial gestalt and 2 (.22) went on to solve the problem; 30 produced gestures representing *different* spatial gestalts and 13 (.43) went on to solve the problem. These proportions are not statistically different from each other but run counter to the predicted direction.

Similarities Phase

Next we analyzed whether what people mentioned in the similarities phase predicted whether they would go on to solve the problem (see Table 2). Many participants noted superficial similarities between the stories, such as that both involved a strong protagonist, a problem that a group of people faced, or a change of strategy. But the focus of our analysis was whether participants mentioned redistribution and, further, whether these mentions were generic or story-specific. 22/78 (.28) people produced a generic mention of redistribution in one modality or another: 2 did so only in speech, 6 did so only in gesture, and 14 did so in speech-gesture combinations. Of these 22, 15 (.68) went on to solve the radiation problem, compared to 20 of the 56 people (.36) who did not produce a generic mention of redistribution ($\chi 2$= 5.48, 1 df, n= 78, p= .02, Cramer's V= .29). This pattern replicates Gick & Holyoak's (1983) finding that solution success on the radiation problem is predicted by whether participants identify solution-relevant similarities between the stories. Note that because 20/22 (.91) *generic* mentions of redistribution involved gesture, it is not possible to meaningfully compare those mentions that involved gesture with those that did not.

Finally, we examined whether story-specific mentions of redistribution during the similarities phase predicted success in the same way that generic mentions did. Of those 56 participants who did not make a generic mention of redistribution, 22 produced one or more story-specific mentions of redistribution and 8 (.36) went on to solve the problem. By comparison, of the 34 participants who never mentioned redistribution, either generically or story-specifically, 12 (.35) went on to solve the problem. Story-specific mentions of redistribution thus do not appear to predict solution success, while generic mentions do. Note also that, like the generic mentions, story-specific mentions were almost always accompanied by gesture (21/22), making it impossible to meaningfully compare those that involved gesture to those that did not.

Discussion

We predicted that gesturing about the redistribution strategy, whether during the story or similarities phase, would lead to success on the radiation problem. What we found instead was a more nuanced relationship between gesture and solution success. Redistribution gestures produced in the story phase, while initially retelling the General and Fire Chief story, were predictive of a *failure* to solve the radiation problem. Even when participants produced the same helpful redistribution gesture, first in one story and then immediately after in the next story, they were no better off. In the similarities phase, gestures produced when mentioning redistribution as a generic feature of both stories were inextricably co-produced with speech. But they apparently did not get in the way of success on the radiation problem and may have even helped. These results suggest, not only that gesture may play an important predictive role in analogical problem solving, but also that it may have distinct effects at different stages of the process.

Consistent with previous observations about gesture form, the gestures produced in both phases of our study were highly schematic, representing the pared-down essences of spatial concepts such as division (e.g. two fists pulled apart)

or surrounding (e.g. an index finger tracing a circle). In the story phase, participants in some cases produced qualitatively similar, highly schematic redistribution gestures in both the General and Fire Chief stories. The key to solving the radiation problem was thus not only right under our participants' noses but actually in their hands. And yet these helpful concepts proved elusive only minutes later. How could this be? The answer we suggest is that gesture form can be deceiving. A participant who produces a gesture in the story phase that appears to be highly schematic may actually have in mind concrete and detailed imagery tied to the particular story being described. Producing a gesture in this case may serve to maintain or even further entrench such imagery in all its richness (Wesp et al., 2001). On this account, the schematic form that a gesture takes may be due more to motor constraints than to the schematic nature of the mental imagery that underlies it.

The gestures produced in the similarities phase were also highly schematic. In fact, examining a redistribution gesture produced in the stories phase alongside a redistribution gesture produced in the similarities phase, it is very difficult, if not impossible, to tell them apart (see Figure 1). In the same way, within the similarities phase it is very difficult to identify differences between a gesture produced in the context of a generic mention of redistribution and one produced in the context of a story-specific mention. And yet these gestures appear to play very different roles depending on the context in which they are produced. Thus one possible moral for future research is that you cannot judge a gesture by its form alone. Gestures associated with generic mentions of redistribution in the similarities phase are likely motivated by imagery that is no longer tied to a particular story but highly schematic. Producing a gesture in this case may also serve to maintain or further entrench the imagery underlying it but at this stage this is no longer hurtful: once a spatial abstraction such as the redistribution strategy has taken shape in the mind, gesturing about it may only serve to make it all the more robust. Of course, whether gesture actually helps make such abstractions more robust— or merely does no harm— is an important question that our study leaves open.

On a cautionary note, because the results of this first study are correlational, it is difficult to tell whether gesture is an active ingredient in analogical problem solving or a correlate of other active ingredients. One alternative explanation for the correlation we observed is that gestures may be more likely to be produced when imagery is particularly vivid (Hostetter & Alibali, 2008). If this is the case, then the strength of the imagery underlying that gesture— rather than gesture *per se*— might be what hinders transfer in the story phase. And since the imagery underlying generic redistribution gestures produced in the similarities phase is likely more schematic, the fact that it is strong may no longer hinder transfer. Another alternative explanation is that, given recent findings that gesture is more likely to be produced by individuals with poor spatial reasoning ability (Chu et al., 2013), one could predict that those who gesture might be just the individuals who would have difficulty with the radiation problem, which involves a spatial insight. Further studies manipulating gesture directly will be required to clarify why gesture plays the predictive role that it does in this paradigm.

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