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Spontaneous Gestures Influence Strategy Choices in Problem Solving

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Abstract

Do gestures merely reflect problem-solving processes, or do they play a functional role in problem solving? We hypothesized that gestures highlight and structure perceptual-motor information, and thereby make such information more likely to be used in problem solving. Participants in two experiments solved problems requiring the prediction of gear movement, either with gesture allowed or with gesture prohibited. Such problems can be correctly solved using either a perceptual-motor strategy (simulation of gear movements) or an abstract strategy (the parity strategy). Participants in the gesture-allowed condition were more likely to use perceptual-motor strategies than were participants in the gesture-prohibited condition. Gesture promoted use of perceptual-motor strategies both for participants who talked aloud while solving the problems (Experiment 1) and for participants who solved the problems silently (Experiment 2). Thus, spontaneous gestures influence strategy choices in problem solving.

Keywords

gesture, problem solving, embodiment, strategy choice

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When solving problems, people often select a strategy from among several possible options. What factors influence strategy choices? Past research has focused on characteristics of the problems, the context, and the solvers (e.g., Ellis, 1997; Imbo & LeFevre, 2009; Lemaire & Callies, 2009; Siegler, 1996). Here we consider another possible factor: solvers' body movements, and, in particular, their spontaneous manual gestures. Recent theoretical work suggests that gestures are based on simulations of perceptual states and actions (Hostetter & Alibali, 2008). We investigated whether gestures influence problem-solving strategies by supporting mental simulations relevant to the problems.

There is extensive evidence that gestures are involved not only in communicating perceptual-motor information (Beattie & Shovelton, 2002; de Ruiter, 1998; Feyereisen & Havard, 1999; Kita, 2000; Trafton et al., 2005), but also in thinking about perceptual-motor information. Gestures can reflect how people mentally represent problems (e.g., Alibali, Bassok, Solomon, Syc, & Goldin-Meadow, 1999; Hegarty, Mayer, Kriz, & Keehner, 2005) and whether people are ready to learn new concepts (e.g., Church & Goldin-Meadow, 1986; Pine, Lufkin, & Messer, 2004). Furthermore, gestures influence learning and problem solving in various ways: They can bring out implicit knowledge (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007), facilitate spatial visualization (Chu & Kita, 2011), and introduce or highlight perceptual-motor information in problem representations (Alibali & Kita, 2010; Beilock & Goldin-Meadow, 2010; Boncoddo, Dixon, & Kelley, 2010). However, as yet, it is not known whether gestures can influence strategy choices in problem solving.

We reasoned that if gestures highlight and structure perceptual information, producing gestures would make such information more likely to be used in problem solving. We tested this hypothesis using a task involving the prediction of gear movement. With experience on this task, participants transition from using perceptual-motor strategies (e.g., depicting the movements of each gear) to using abstract strategies (e.g., the parity strategy, which involves noting whether the number of gears is odd or even; Schwartz & Black, 1996). We predicted that participants who are prohibited from gesturing would use perceptual-motor strategies less often, and thus be more likely to transition to abstract strategies, compared with participants who are allowed to gesture. In particular, we expected that participants who are prohibited from gesturing would be more

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likely to generate the parity strategy than would participants who are allowed to gesture.

Experiment 1

Method

Participants. Participants were 88 undergraduates from an American public university. Two were excluded from analysis because of experimenter error, and 1 because he had an object in his hands.

Procedure. Participants were randomly assigned to have either their hands or their feet restrained. In the gesture-prohibited (hands-restrained) condition, participants wore "one size fits all" cotton gloves with Velcro attached to the palms, and they gripped two cans that were covered with Velcro and affixed to a board. In the gesture-allowed (feet-restrained) condition, participants' feet were strapped onto a board with Velcro straps. The foot restraint was intended as a control for the "strangeness" of the hand restraint. An opaque screen stood between the experimenter and the participants.

Participants were tested individually. They were asked to think aloud as they solved six problems involving gears in horizontal lines (e.g., "Imagine four gears are arranged in a horizontal line. If you turn the gear on the left clockwise, what would the gear on the right do?"). Problems involving four, seven, nine, five, eight, and six gears were presented in that order to all participants. After a correct solution, the experimenter proceeded to the next problem, and after an incorrect solution, he allowed the participant to try again.

All sessions were videotaped with a hidden camera. At the end of each session, the participant was informed of the hidden camera, and the experimenter offered to have the data from the session erased; all participants declined this offer.

Coding. Participants' responses were classified in terms of the problem-solving strategies they expressed, taking both speech and gesture into account (Table 1). Most strategies could be classified as *perceptual-motor* strategies, which involve depicting the actions of individual gears, or *abstract* strategies, which involve reasoning based on rules. Participants could express both types of strategies either in speech alone or in gesture and speech together. For example, participants sometimes gestured to simulate gear actions and sometimes used words without gestures to describe gear actions (e.g., "the first turns clockwise, the next counterclockwise . . . "). Two independent coders coded the responses for all problems and then reevaluated problems on which they disagreed (8.7% of trials).

For participants in the gesture-allowed condition, gestures were also coded. A coder assessed whether each response included (a) rotating gestures, which simulated gear movements (e.g., turning the hand clockwise); (b) ticking gestures (e.g., up-and-down movements that traversed space, as if the participant was counting gears); or (c) other kinds of gestures (e.g., single up-and-down beat gestures or single points). Each

Table 1. Strategy Codes, Definitions, and Examples From Experiment 1

Strategy	Definition	Example
Perceptual-motor strategies		
Depict all	Participant models the actions of each individual gear	"The first one goes clockwise [clockwise rotation gesture], the next one goes counterclockwise [counterclockwise rotation gesture], clockwise [clockwise rotation gesture], counterclockwise [counterclockwise rotation gesture]."
Depict chain	Participant starts from a solution to a previous problem and models the actions of each individual gear after that point	"With four gears, it went counterclockwise, so five clockwise [ticking gesture], six counterclockwise [ticking gesture], seven clockwise [ticking gesture]."
Abstract strategies		
Parity	Participant notes that if the number of gears is even, the target gear will turn in a direction opposite to the first gear; if the number of gears is odd, the target gear will turn in the same direction as the first	"It's an odd number so it will go clockwise, like the first one."
Incorrect rule	Participant uses an incorrect rule, such as "all gears turn in the same direction"	"The first one went clockwise, so the other ones go clockwise too."
Other strategies		
Guess	Participant states that he or she guessed in order to arrive at a solution	"I guessed."
No strategy	Participant offers the solution only, without stating how the solution was reached	"Clockwise."

Note: Strategies were coded with both speech and gesture taken into account.

trial was classified as including rotating, ticking, both ticking and rotating, other, or no gestures. A second coder assessed the data for 12% of participants; agreement was 93% (κ = .91).

Results

The mean proportion of correct solutions was identical in the two conditions (gesture allowed: M = .91, SD = .14; gesture prohibited: M = .91, SD = .12). This similarity was expected, because both perceptual-motor and abstract strategies can yield correct answers.

Table 2 summarizes the strategies used by participants in the gesture-allowed condition when they produced different types of gestures. Thirty-eight of the 42 participants in the gesture-allowed condition produced gestures. Overall, participants in this condition produced rotation gestures on an average of 27% of trials (SD = 25) and ticking gestures on an average of 25% of trials (SD = 30). Participants were less likely to use abstract strategies (and more likely to use perceptual-motor strategies) when they produced rotating or ticking gestures than when they produced no gestures. We analyzed these data using mixed-effects logistic regression, with use of an abstract strategy (yes/no) as the dependent variable, production of gesture (yes/no) as a fixed factor, and participant as a random factor. Among participants who produced some trials with no gesture and some trials with rotating gestures (n = 21), participants used abstract strategies more often on trials with no gesture (M = .81, SD = .36) than on trials with rotating gestures (M = .20, SD = .31), β = 3.35, Wald Z = 5.38, $p < .001$. Among participants who produced some trials with no gesture and some trials with ticking gestures (n = 12), participants used abstract strategies more often on trials with no gesture (M = .82, SD = .32) than on trials with ticking gestures (M = .39, SD = .49), β = 3.81, Wald Z = 3.57, $p < .001$. In both cases, the model with gesture fit the data better than the model without gesture, $\chi^2(1) = 13.68$, $p < .001$, and $\chi^2(1) = 32.53$, $p < .001$, respectively.[1]

We predicted that participants in the gesture-allowed condition would be less likely than participants in the gesture-prohibited condition to generate the parity strategy, because the availability of gesture would promote use of perceptual-motor strategies instead. This was indeed the case; the proportion of participants who used the parity strategy on at least one trial was .74 in the gesture-allowed condition and .91 in the gesture-prohibited condition, $\chi^2(1, N = 85) = 4.17$, $p = .04$ (Fig. 1). Once they generated the parity strategy, most participants (89%) used it on all subsequent trials.

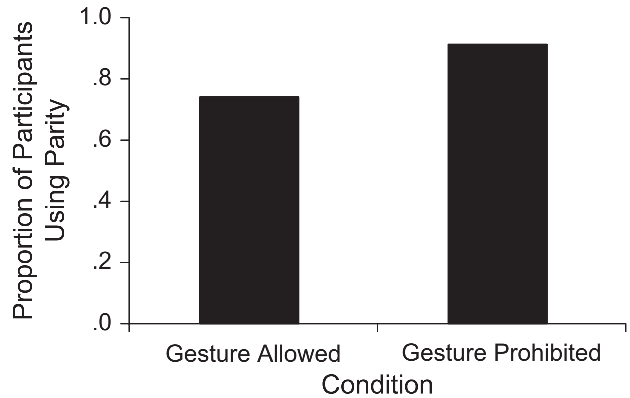

Fig. 1. Proportion of participants in the gesture-prohibited and gesture-allowed conditions of Experiment 1 who used the parity strategy on at least one trial.

We also examined participants' use of the parity strategy at the level of the individual trial. To do so, we compared three types of trials: (a) trials on which participants were allowed to gesture and did so; (b) trials on which participants were allowed to gesture but chose not to do so; and (c) trials on which participants were not allowed to gesture by design (i.e., the gesture-prohibited condition). For these comparisons, we used mixed-effects logistic regression, with use of the parity strategy (yes/no) as the dependent variable, trial type as a fixed factor, and participant as a random factor. Parity was used on a smaller percentage of trials when participants were allowed to gesture and did so (30%) than when they did not gesture, either by choice (76%), β = 3.28, Wald Z = 5.97, $p < .001$, or by design (52%), β = 1.18, Wald Z = 3.42, $p < .001$.[2] In each case, the model with trial type as a factor provided a better fit to the data than the model without this factor, $\chi^2(1) = 42.7$ and $\chi^2(1) = 10.99$, respectively, both ps < .001.[3]

Regardless of condition, many participants used the parity strategy for the first time early in the problem set (typically on Trial 2; see Table 3, which presents the number of participants who used the parity strategy for the first time on each trial, as well as the total number who used the parity strategy and who used perceptual-motor strategies on each trial). The difference between conditions evident in Figure 1 reflects mainly the second half of

Table 2. Results for the Gesture-Allowed Condition in Experiment 1: Proportion of Trials With Each Gesture Type That Were Solved Using Each of the Three Strategy Types

	Gesture type				
Strategy type	No gesture	Rotating	Ticking	Rotating and ticking	Other
Abstract	.76	.31	.18	.31	.65
Perceptual-motor	.22	.63	.82	.69	.35
Other	.02	.06	.00	.00	.00
Number of trials	118	54	49	13	17

Table 3. Results From Experiment 1: Number of Participants in Each Condition Who Used Parity for the First Time on Each Trial, Who Used Parity on Each Trial, and Who Used Perceptual-Motor Strategies on Each Trial

	Used the parity strategy for the first time on the trial		Used the parity strategy on the trial		Used perceptual-motor strategies on the trial	
Trial number	Gesture allowed	Gesture prohibited	Gesture allowed	Gesture prohibited	Gesture allowed	Gesture prohibited
1	1 (.02)	1 (.02)	1 (.02)	1 (.02)	39 (.93)	40 (.93)
2	17 (.40)	16 (.37)	18 (.43)	16 (.37)	23 (.55)	23 (.53)
3	8 (.19)	6 (.14)	25 (.60)	23 (.53)	16 (.38)	18 (.42)
4	1 (.02)	7 (.16)	25 (.60)	28 (.65)	16 (.38)	13 (.30)
5	3 (.07)	7 (.16)	30 (.71)	32 (.74)	11 (.26)	9 (.21)
6	1 (.02)	2 (.05)	31 (.74)	35 (.81)	10 (.24)	8 (.19)
Never	11 (.26)	4 (.09)	11 (.26)	4 (.09)	3 (.07)	2 (.05)

Note: The numbers in parentheses indicate the proportion of participants in each cell.

the experiment; more participants in the gesture-prohibited condition than in the gesture-allowed condition used the parity strategy for the first time in the second half of the problem set. Thus, most participants in the gesture-allowed condition who generated the parity strategy did so in the first half of the set. In contrast, in the gesture-prohibited condition, many participants generated the parity strategy in the first half of the set, but many others did so in the second half, $\chi^2(1, N = 70) = 5.10$, $p = .02$.

Discussion

This experiment tested whether the availability of gesture influences strategy choices. In the gesture-allowed condition, gesture was more strongly associated with perceptual-motor strategies than with abstract strategies. More crucially, participants who were prohibited from gesturing were more likely than participants who were free to gesture to abandon perceptual-motor strategies and generate the parity strategy. Roughly half the participants in both conditions used this strategy in the first half of the problem set, but subsequent strategy choices differed between conditions. Very few participants in the gesture-allowed condition generated the parity strategy in the second half of the problem set, but a substantial number of participants in the gesture-prohibited condition did so. We suggest that participants who were allowed to gesture continued to use perceptual-motor strategies because gesture enhanced activation of such strategies.

In this experiment, participants' talk-aloud protocols allowed us to assess strategies on each trial. However, it is unclear whether the results hinged on participants' talking aloud. Does the availability of gestures directly influence problem-solving strategies, or does it influence talking aloud, which in turn influences strategies? Experiment 2 addressed this issue.

Experiment 2

In our second experiment, participants solved gear problems silently, with gesture allowed or prohibited. We interviewed participants about their strategy use after they solved all the problems.

Method

Participants. Participants were 111 adults from the Birmingham (United Kingdom) area. Two were excluded from analyses, 1 for not following instructions and 1 because the video cut off before the session ended.

Procedure. Participants were randomly assigned to gesture-allowed and gesture-prohibited conditions. Participants in the gesture-allowed condition solved the problems without any restraint of their bodies. Participants in the gesture-prohibited condition were asked to sit on their hands.

The experimenter read the problems aloud, and participants' responses were videotaped. Problems were presented in a fixed order (four, seven, nine, five, eight, and six gears), with the starting problem varied across participants. After participants offered a solution for a problem, the experimenter stated whether the solution was correct and proceeded to the next problem. After the final problem, the experimenter asked participants how they had solved the problems and whether they had used the parity strategy. Participants sometimes described a single strategy and sometimes described shifting strategies (e.g., "The first one, I had to work through in my mind what exactly would happen; then [I] realized the pattern of odd and even"). On the basis of these responses, we coded whether each participant used the parity strategy or not.

Gesture coding. Gestures were comparable to those produced by participants in Experiment 1 and were coded in the same way. A second coder assessed the data for 11% of participants; agreement was 90.5% ($\kappa = .80$).

Results

To compare problem solutions across conditions, we utilized mixed-effects logistic regression with correctness as the dependent variable, condition as a fixed factor, and participant and item as random factors. The percentage of correct solutions did not differ by condition (gesture allowed: M = 89%, SD = 18; gesture prohibited: M = 86%, SD = 16), β = 0.30, Wald Z = 0.91, p = .36.

Twenty-eight of the 52 participants in the gesture-allowed condition produced gestures; the other 24 were classified as "spontaneous nongesturers." Overall, participants in the gesture-allowed condition produced rotation gestures on an average of 13% of trials (SD = 23) and ticking gestures on an average of 10% of trials (SD = 22).

Participants in the gesture-prohibited condition were more likely to generate the parity strategy than were participants in the gesture-allowed condition who produced gestures, $\chi^2(1, N = 85) = 3.85, p < .05$ (Fig. 2). Furthermore, among the participants in the gesture-allowed condition, spontaneous nongesturers were significantly more likely to generate the parity strategy than were gesturers, $\chi^2(1, N = 52) = 6.52, p = .01$ (Fig. 2).[4]

Discussion

This experiment tested whether gesture influences strategy choices even when participants do not talk aloud. Participants who were not allowed to gesture were more likely to generate the parity strategy than were those who produced gestures.

Could this pattern be a side effect of gesture prohibition (i.e., due to discomfort or distraction, rather than absence of gesture per se)? We consider this unlikely, because participants in the gesture-prohibited condition performed *better* than those in the gesture-allowed condition—more of them generated the more efficient parity strategy. The spontaneous nongesturers provide further evidence for our interpretation. Both gesturers and spontaneous nongesturers were allowed to gesture, so neither of these groups experienced gesture prohibition. Yet like participants who were prohibited from gesturing, spontaneous nongesturers were more likely than gesturers to generate the parity strategy. Taken together, our data indicate that the absence of gesture promoted the shift to the parity strategy (and that this shift was not a side effect of gesture prohibition).

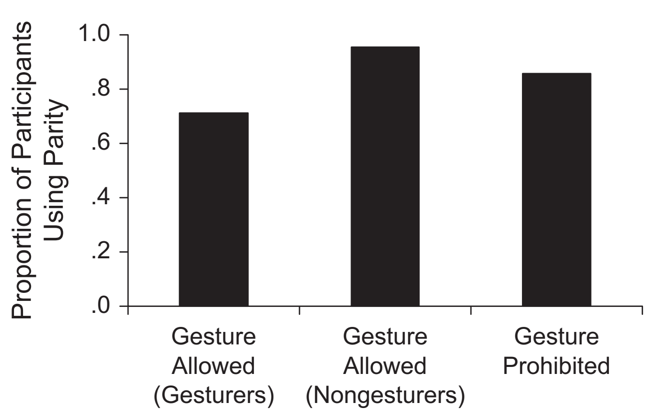

Fig. 2. Proportion of participants in the gesture-prohibited and gesture-allowed conditions of Experiment 2 who used the parity strategy on at least one trial. Participants in the gesture-allowed condition were divided into two groups: gesturers and spontaneous nongesturers.

General Discussion

This research demonstrates that gestures influence strategy choices in problem solving. When solving problems involving gear movement (either talking aloud or silently), participants who were prohibited from gesturing were more likely than those who gestured to abandon strategies based on simulation of gear movements and to shift to the abstract, parity strategy. This finding was robust over minor procedural variations across the two experiments, and it held in two different populations (United States, United Kingdom). Our results suggest that gestures highlighted and structured perceptual-motor information for simulation of gear movements and thus promoted simulation-based strategies.

We found that both rotation and ticking gestures tended to accompany perceptual-motor strategies, rather than abstract strategies. Rotation gestures reflect simulation of gear movements, and ticking gestures reflect the layout of the gears in simulated space (see Schwartz & Black, 1996). In two experiments that manipulated the availability of gesture, problem solvers who produced gestures were more likely than nongesturers to utilize strategies based on perceptual-motor information. Thus, gestures are not simply an indicator that actions or perceptual states are being simulated (Hostetter & Alibali, 2008). Instead, we suggest, producing gestures actually raises the level of activation of relevant perceptual-motor information, and thereby influences strategy choices. In the case of the gear problems used in this study, producing gestures facilitated mental simulation of physical movements and spatial positions.

Our findings add to the growing evidence that gesture facilitates cognitive processes, including both processes involved in speaking—such as activating visuospatial information (e.g., Wesp, Hess, Keutmann, & Wheaton, 2001), packaging spatio-motor information into units relevant for speaking (e.g., Alibali, Kita, & Young, 2000; Kita, 2000), and accessing words with spatial content (e.g., Rauscher, Krauss, & Chen, 1996)—and processes involved in problem solving, such as spatial visualization (e.g., Chu & Kita, 2011), constructing problem representations (e.g., Beilock & Goldin-Meadow, 2010; Boncoddo et al., 2010), and bringing out implicit knowledge in spatio-motoric format (Broaders et al., 2007). In all these cases, gestures serve to highlight and structure perceptual-motor information.

Our findings also align with other evidence that actions influence problem solving. For example, Martin and Schwartz (2005) showed that the opportunity to physically act on fraction manipulatives, as opposed to simply drawing on pictures of the materials, led children to structure fraction problems differently and consequently yielded benefits for the children's problem solving.

The effects of gestural facilitation of mental simulation may vary, depending on the nature of the problems. In this study, producing gestures made it less likely that speakers would generate the highly efficient parity strategy; thus, gesture could be considered detrimental. However, when perceptual-motor information is important for problem solving (e.g., in mental rotation), gestures can be beneficial (Chu & Kita, 2011). Future work is needed to establish how the value of perceptual-motor strategies varies as a function of the material characteristics of the problems, problem solvers' knowledge, and future performance demands, as well as how various types of actions (gesturing, drawing, acting on objects) differ in their effects on problem solving.

Our findings shed new light on the role of gesture in problem solving, and specifically in strategy choice. Past studies (e.g., Alibali & Goldin-Meadow, 1993; Goldin-Meadow, Cook, & Mitchell, 2008) have implicated gesture in processes of cognitive change, but have not pinned down all of the mechanisms involved. The work reported here suggests that highlighting and structuring perceptual-motor information is one key mechanism.

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Declaration of Conflicting Interests

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Notes

1. We could not statistically compare strategy use on trials with no gesture and trials with both rotating and ticking gestures, because only 5 participants produced trials of both types. Four of these participants used the parity strategy on all trials with no gesture and perceptual-motor strategies on all trials with rotating and ticking gestures. The remaining participant used the parity strategy on both no-gesture trials and trials with rotating and ticking gestures.
2. The first reported comparison is a within-subjects comparison on the subset of participants from the gesture-allowed condition who gestured on some trials and did not gesture on other trials (n = 28). The second is a between-subjects comparison; trials with gesture were taken from participants in the gesture-allowed condition who gestured on some or all trials (n = 38), and trials without gesture were taken from participants in the gesture-prohibited condition (n = 43), who were prevented from producing gestures on all trials.
3. Participants who were not allowed to gesture used the parity strategy on a larger percentage of trials than did participants who were allowed to gesture but chose not to do so, $\beta = 2.00$, Wald $Z = 3.81$, $p < .001$. The model that included trial type fit the data better than the model that did not, $\chi^2(1) = 15.13$, $p < .001$.
4. The likelihood of generating the parity strategy did not differ significantly between spontaneous nongesturers in the gesture-allowed condition and participants in the gesture-prohibited condition, $\chi^2(1, N = 81) = 1.7$, $p = .20$.

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