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Gesture Changes Thought by Grounding It in Action

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Abstract

When people talk, they gesture. We show that gesture introduces action information into speakers' mental representations, which, in turn, affect subsequent performance. In Experiment 1, participants solved the Tower of Hanoi task (TOH1), explained (with gesture) how they solved it, and solved it again (TOH2). For all participants, the smallest disk in TOH1 was the lightest and could be lifted with one hand. For some participants (no-switch group), the disks in TOH2 were identical to those in TOH1. For others (switch group), the disk weights in TOH2 were reversed (so that the smallest disk was the heaviest and could not be lifted with one hand). The more the switch group's gestures depicted moving the smallest disk one-handed, the worse they performed on TOH2. This was not true for the no-switch group, nor for the switch group in Experiment 2, who skipped the explanation step and did not gesture. Gesturing grounds people's mental representations in action. When gestures are no longer compatible with the action constraints of a task, problem solving suffers.

Keywords

gesture, action, embodied cognition, problem solving

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When people describe how they perform activities such as tying their shoes, rotating gears, or balancing blocks, they frequently gesture (Pine, Lufkin, & Messer, 2004; Schwartz & Black, 1996). The information conveyed in these gestures often reflects the actions executed on the objects being described (Cook & Tanenhaus, 2009) and is not conveyed in accompanying speech (Goldin-Meadow, 2003; Stevanoni & Salmon, 2005). We investigated the cognitive consequences of these action gestures, not for listeners, but for the gesturers themselves.

Research suggests that how people act influences how they think by grounding perception, affect, and even language comprehension in the sensorimotor systems used to interact with the world (Barsalou, 1999; Beilock, Lyons, Mattarella-Micke, Nusbaum, & Small, 2008; Glenberg & Robertson, 2000; Niedenthal, 2007; Zwaan, 1999). For example, learning to produce specific walking movements (without visual feedback) aids one's ability to later visually discriminate these movements, presumably because discrimination becomes tied to the sensorimotor systems used in moving (Casile & Giese, 2006). We hypothesize that, just as action influences subsequent thought, the action information expressed in gesture may also influence subsequent thought. Gesture may influence speakers' own thoughts by adding action information to their mental representations.

Our hypothesis is motivated by the *embodied-cognition* framework—in particular, the claim that off-line cognition (i.e., the internal representation of information not present in the environment) is accomplished by simulating actions that could be or have been used in the world (Wilson, 2002; see Chambers, Tanenhaus, Eberhard, Filip, & Carlson, 2002; Wilson & Knoblich, 2005). Hostetter and Alibali (2008) hypothesized that gesture is an explicit expression of this action simulation. We take this hypothesis one step further. We suggest that gesture not only is a vehicle for expressing action information, but also, because it is itself action, can add action information to the gesturer's mental representations.

In two experiments, participants performed the Tower of Hanoi task (TOH; Newell & Simon, 1972; Fig. 1, top), in which the goal is to move a stack of disks, arranged in order of size with the largest disk on the bottom and the smallest disk on the top, from one of three pegs to another peg; a larger disk can never be placed on top of a smaller disk, and only one disk can be moved at a time. Experiment 1 contained three parts: Participants (a) solved the TOH problem (TOH1), (b) used

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Fig. 1. Illustration of the Tower of Hanoi task and participants' gestures in explaining how they solved the task. The photograph at the top shows a participant using two hands to move the largest and heaviest disk from one peg to another in the first task (TOH1); the four disks weighed 2.9, 2.3, 1.6, and 0.8 kg, respectively. Although the smallest disk was the lightest and could be moved with one hand in TOH1, participants produced one-handed (bottom left) and two-handed (bottom right) gestures while explaining how they moved that disk.

both speech and gesture to explain how they solved the problem, and (c) solved it again (TOH2). For all participants, the smallest disk in TOH1 was the lightest (0.8 kg) and could be lifted with one hand. For some participants (*no-switch group*), the smallest disk remained the lightest in TOH2. For other participants (*switch group*), the smallest disk was switched to be the heaviest (2.9 kg) in TOH2 and, because it was so heavy, could be lifted only by using two hands.

Participants could use either one-handed or two-handed gestures to represent moving the smallest (and lightest) disk in their explanations of how they solved TOH1. But note that for the switch group, one-handed gestures were incompatible with the two-handed actions needed to pick up the smallest (and heaviest) disk in TOH2. We hypothesized that producing one-handed gestures while explaining TOH1 would change participants' mental representation of the TOH task. If so, then the mental representations of switch-group participants who used one-handed gestures would not be compatible with the TOH2 task they were about to solve, and the switch group would perform worse than the no-switch group on TOH2. Moreover, if gesture truly caused such group differences, then the more one-handed gestures participants in the switch group used to depict moving the smallest disk, the worse their TOH2 performance would be.

Experiment 1

Method

Participants. Participants (no-switch group: n = 12; switch group: n = 14) were recruited for a study examining "object manipulation."

Procedure. All participants gave informed consent and were tested individually. They first solved four practice TOH trials. The first three trials used a simple three-disk version to acquaint participants with the task. The fourth practice trial used the four-disk TOH task that participants would encounter on the trials of interest. For all practice trials, disk size correlated with weight. After each practice trial, participants were asked to explain to the experimenter how they solved the problem and to use their hands during their explanations.

The experiment began with participants solving a four-disk TOH task (TOH1). The time taken to solve TOH1 served as a baseline against which to compare performance on the TOH task after the weight of the disks was manipulated. Pilot testing revealed that when participants initially solved TOH1 in less than 65 s, they had little room to improve (i.e., it was impossible to test for learning). Therefore, because we wanted to explore the impact of our experimental manipulation on TOH learning, only participants who solved TOH1 in more than 65 s were included in our analyses.

After solving TOH1, participants were led into another room and asked to explain to a confederate how they solved the task. To ensure uniformity across participants, we again asked everyone to use their hands while offering their explanations. However, pilot testing revealed that almost everyone gestures without this prompt. From the participants' perspective, the confederate was another participant, familiar with TOH rules, but with no experience solving the task.

Finally, all participants returned to the first room, where they again solved a four-disk TOH problem (TOH2). Some participants solved the same version they had solved originally (no-switch group). Other participants solved a version in which the weights of the disks were reversed (switch group). In this case, the smallest disk was the heaviest, and the largest disk the lightest. When the smallest disk weighed the least, it could be lifted with one hand. But when it weighed the most, it was too heavy to be lifted with one hand and required two hands to be lifted successfully. In all other respects, the switched disks in TOH2 looked identical to the unswitched disks, and the disks had been discretely replaced while participants were in the other room. Following TOH2, participants were debriefed.

Results and discussion

The difference in problem-solving time (TOH2 – TOH1, in seconds) was our main performance measure.[1] This measure was highly correlated with the difference in number of moves used to solve the task ($r = .83$, $p < .0001$).

Changing the weights of the disks for TOH2 had a significant impact on performance (see Fig. 2). As expected, practice improved performance for the no-switch group, for whom the disk weights were unchanged. The no-switch group solved TOH2 in less time than TOH1 (mean difference = –31.7 s, SE = 12.9 s). In contrast, the switch group took longer to solve TOH2 than TOH1 (mean difference = 2.8 s, SE = 8.9 s). The significant Task (TOH1, TOH2) × Group (no-switch, switch) interaction, $F(1, 24) = 5.05$, $p < .04$, confirmed that change in performance from TOH1 to TOH2 was dependent on whether the weights of the disks had changed.

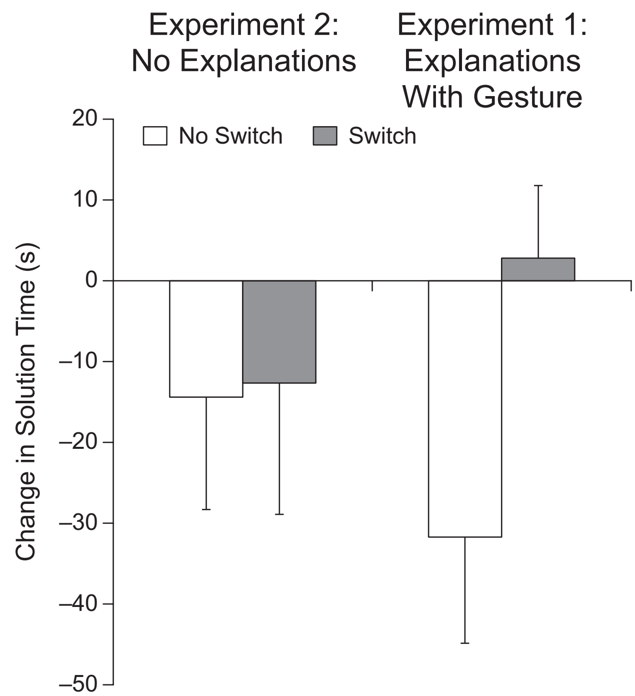

Fig. 2. Change in time taken to solve the Tower of Hanoi (TOH) problem as a function of experimental group. Change in solution time was calculated by subtracting time taken to solve the first TOH problem (TOH1) from time taken to solve the second TOH problem (TOH2). In Experiment 1 (right-hand bars), participants explained (with gesture) how they solved TOH1 before they attempted TOH2, and in Experiment 2 (left-hand bars), participants gave no explanations between TOH1 and TOH2 and therefore did not gesture. For both experiments, results are shown separately for participants in the switch and no-switch groups.

Why did changing the disks' weights influence TOH performance? Note that disk weight is not relevant to solving the TOH problem. Thus, when participants explained how they solved TOH1 to the confederate, they never talked about the weight of the disks or the number of hands they used to move the disks.[2] Disk weight was, however, often reflected in gesture, and the particular gestures used when explaining TOH1 had an impact on TOH2 solution time.

When the switch and no-switch groups explained how they solved TOH1 (in which the smallest disk was the lightest), some participants in both groups used one-handed gestures while talking about how they moved the smallest disk (Fig. 1, bottom left), and others used two-handed gestures (Fig. 1, bottom right). When it came time to solve TOH2, participants in the switch group could no longer lift the smallest disk with one hand. The one-handed gestures that they produced when explaining TOH1 were therefore incompatible with the actions needed to solve TOH2. There was no incompatibility for the no-switch group because their disk weights had not changed.

The more incompatible (i.e., one-handed) gestures the switch group produced in describing moving the smallest disk, the longer they took to solve TOH2 relative to TOH1 ($r = .55$, $p < .05$; Fig. 3, right panel). For the no-switch group, there was no relation between percentage of one-handed gestures and change in performance from TOH1 to TOH2 ($r = -.37$, $p > .24$; Fig. 3, left panel).

Did the number of hands that participants actually used when acting on the smallest disk in TOH1 influence TOH2 performance? If so, gesture might merely have reflected participants' previous action experience. This was not the case, however. The between-group difference in change in performance across TOH attempts (i.e., TOH2 – TOH1) did not depend on the percentage of one-handed actions participants used to move the smallest disk when solving TOH1 (i.e., there was no Group × Hand Movement interaction, $p > .1$). Rather, this between-group difference was dependent only on the percentage of one-handed gestures used to describe the smallest disk. The significant Group × Hand Gesture interaction, $\beta = 1.15$, $t(22) = 2.19$, $p < .04$, remained significant when the number of hands used to act on the smallest disk during TOH1 was used as a covariate, $\beta = 1.13$, $t(21) = 2.08$, $p <. 05$.

Switch-group participants did not merely take longer to pick up the smallest disk in TOH2. Rather, the way in which they solved the task changed as a function of their previous gestures: The greater the percentage of one-handed gestures they used in referring to the smallest disk, the more moves switch-group participants took to solve TOH2 relative to TOH1 ($r = .75$, $p < .01$). This correlation was not reliable for the no-switch group ($r = -.42$, $p > .17$).

We hypothesize that gesturing changed participants' mental representation of the TOH task. After gesturing about the smallest disk with one hand, participants mentally represented this disk as a light object that could be moved with one hand. For the switch group, this representation was incompatible with the disk encountered in TOH2 (the smallest disk was too heavy to lift with one hand). The relatively poor performance of the switch group on TOH2 suggests that the mental representation created by gesture interfered with subsequent TOH2 performance.

It is possible, however, that the superior performance of the no-switch group merely reflects an encoding-specificity effect (Tulving & Thompson, 1973), in which recall is better when task-irrelevant properties stay the same between encoding (TOH1 and explanation) and retrieval (TOH2). This explanation seems unlikely, as most people solved TOH1 and TOH2 using different numbers of moves, an indication that they likely used different problem-solving strategies. Moreover, when we restricted our analyses to only those participants who solved TOH1 and TOH2 differently, the Task × Group interaction in problem-solving time remained significant, $F(1, 19) = 4.57$, $p < .05$ (to be consistent with previous analyses, we included one-handed TOH1 actions as a covariate).

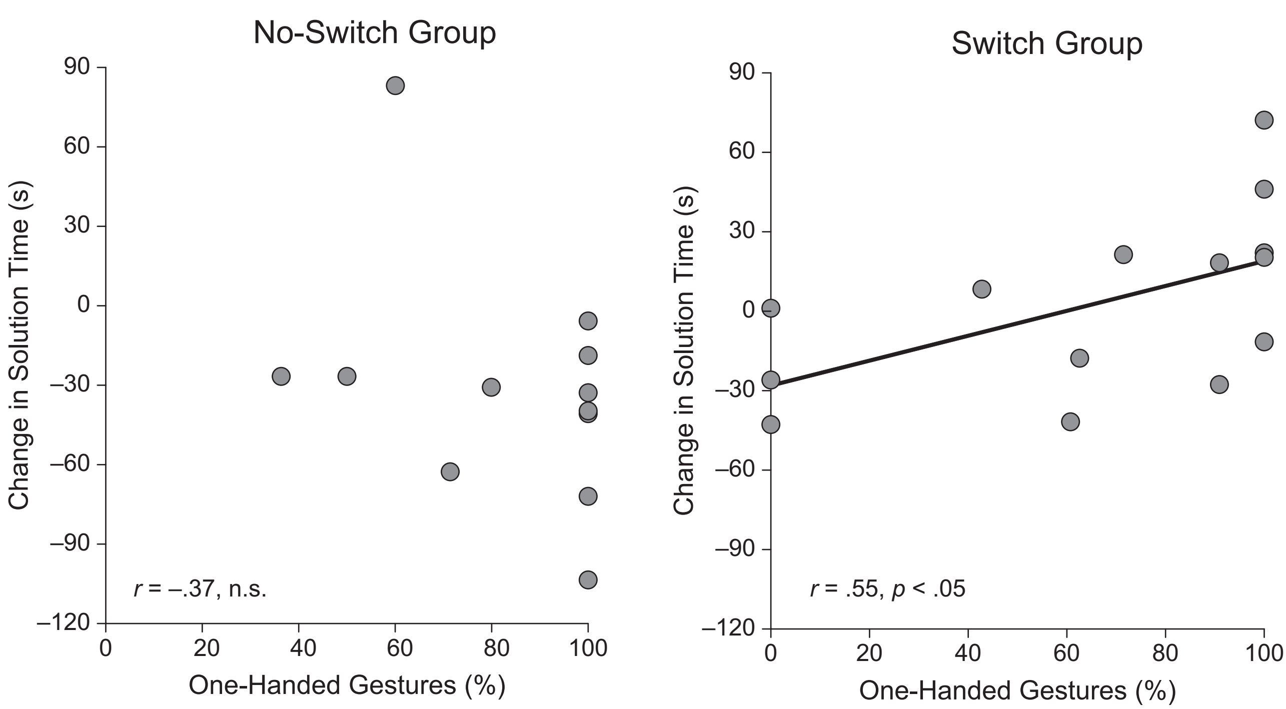

Fig. 3. Change in time taken to solve the Tower of Hanoi (TOH) problem in Experiment 1 as a function of the percentage of one-handed gestures participants used to explain how they solved the first TOH problem. Change in solution time was calculated by subtracting time taken to solve the first TOH problem from time taken to solve the second TOH problem. Results are shown separately for the switch (right panel) and no-switch (left panel) groups.

There is yet another possibility, however: Participants' gestures could have reflected, rather than created, a representation of the smallest disk as a light object. We designed Experiment 2 to test this possibility. Another group of participants performed TOH1 and TOH2, but this time there was no explanation task between problem-solving attempts. If, as we hypothesize, gesture changes thought by adding action information—rather than merely reflecting action information already inherent in the participant's mental representation—then participants who do not gesture between TOH1 and TOH2 should not show a decrement in performance when the disk weights are switched.

Experiment 2

Method

Participants. Participants (no-switch group: $n = 11$; switch group: $n = 9$) were recruited using the same procedures as in Experiment 1.

Procedure. The procedure was identical to that of Experiment 1 with the exception that participants were not asked to explain how they solved TOH1 before solving TOH2. Instead, Experiment 2 participants read a short passage and answered passage-related questions between the two problem-solving attempts. This took roughly the same time as the explanation step in Experiment 1.

Although it might have been more straightforward to ask Experiment 2 participants to explain how they solved TOH1 without gesturing, pilot testing revealed that asking participants not to gesture disrupted their ability to explain the task's solution. People routinely gesture when talking about solving the TOH task (Garber & Goldin-Meadow, 2002), and gesture captures a great deal of information difficult to convey in speech. Because it is hard for participants told not to gesture to fully describe their moves, we could not compare an explanation-without-gesture condition with the explanation-with-gesture condition in Experiment 1.

Results and discussion

On average, participants in Experiment 2 solved TOH2 faster than TOH1 (mean difference = −13.6 s, $SE = 10.3$ s; Fig. 2, left panel), regardless of their group. Reversing disk weights did not affect performance; the Group (no-switch, switch) × Task (TOH1, TOH2) interaction was not significant ($F = 0$).

General Discussion

Gestures communicate (Beattie & Shovelton, 1999; Cassell, McNeill, & McCullough, 1999; Goldin-Meadow & Sandhofer, 1999). But, as we have shown here, they can do more. Gesturing adds action information to people's mental representations of the tasks they explain. If this added information is compatible with the actions required to complete a task, subsequent performance improves. If the added information is incompatible, performance is hindered. In our TOH task, switching the weights of the disks interfered with performance only when participants had previously produced action gestures that were incompatible with subsequent problem-solving attempts. Gesturing while explaining the TOH task changes how gesturers think about the task by adding action information to their mental representations.

Thus, gestures not only reflect simulated action accompanying one's mental representations (Hostetter & Alibali, 2008), but also give rise to action information, presumably because gestures are themselves actions. Gesture's effect on thought is not carried by speech. Indeed, there was no mention of the disks' weight in participants' explanations, and the tendency to mention the smallest disk's size (which was correlated with its weight in TOH1) was unrelated to the percentage of one-handed gestures referring to the smallest disk in both the switch group ($r = -.44$, $p > .1$) and the no-switch group ($r = .11$, $p > .7$). Mentions of the smallest disk's size were also unrelated to the change in performance across TOH attempts (i.e., TOH2 – TOH1; switch group: $r = -.10$, $p > .7$; no-switch group: $r = -.28$, $p > .3$).

Recent work by Cook and Tanenhaus (2009) demonstrated that watching another person's gestures can have an impact on the watcher's subsequent performance. Participants watched spontaneous gestures that either mimicked the way TOH disks are actually lifted or simply traced the trajectory of the disks. All watchers then solved the TOH task on a computer. Participants who saw gestures mimicking actual movements were more likely to make the computer disks follow real-world movements (i.e., they took the disks up and over the peg) than were participants who watched the trajectories; the latter were more likely to move the computer disks laterally from peg to peg. Watchers' problem representations were influenced by the gestures they saw.

Our study extends this work in a significant direction. We have shown that one's own gestures can have an impact on one's subsequent performance. Gesturing does not merely reflect thought: Gesture changes thought by introducing action into one's mental representations. Gesture forces people to think with their hands.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Notes

1. We used a difference score for ease of interpretation. However, raw scores revealed no significant difference between groups on TOH1 (no-switch: $M = 120.9$ s, $SE = 12.1$ s; switch: $M = 109.0$ s, $SE = 9.7$ s; $F < 1$) and a significant group difference on TOH2 (no-switch: $M = 89.2$ s, $SE = 8.9$ s; switch: $M = 111.8$ s, $SE = 11.9$ s), even when TOH1 was used as a covariate, $F(1, 23) = 4.33$, $p < .05$.
2. Although participants did not mention disk weight in speech, calling a disk "small" could lead to representing weight information (i.e., "smaller disks are lighter"). If so, size labeling ought to relate to performance differences between TOH1 and TOH2. To test this hypothesis, we coded how many times participants mentioned the small disk's size. Unlike gesture, frequency of labeling the smallest disk "small" had no relation to change in performance (TOH2 – TOH1) among switch-group participants ($r = -.10$, $p > .7$).

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