

Gesture changes thought by grounding it in action

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## Abstract

When people talk, they gesture. Here we show that gesture introduces action information into speakers' mental representations, which, in turn, impact subsequent performance. In Exp. 1, participants (a) solved the Tower-of-Hanoi task (TOH1); (b) explained (with gesture) how they solved it; (c) solved it again (TOH2). For all participants, the smallest disk in TOH1 was lightest and could be lifted with one-hand. For some participants (*No-Switch Group*), disks in TOH2 were identical to TOH1. For others (*Switch Group*), disk weights in TOH2 were reversed (smallest disk=heaviest and could not be lifted one-handed). We found that 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 Exp. 2 who skipped the explanation step and did not gesture. Gesturing grounds people's mental representations in action. When these gestures are no longer compatible with the action constraints of the task, problem solving suffers.

### **Gesture changes thought by grounding it in action**

When people describe how they perform activities such as tying their shoes, rotating gears, or balancing blocks, they frequently gesture (Pine et al., 2004; Schwartz & Black, 1996). The information conveyed in speakers' hand gestures often reflects the actions they have executed on these objects (Cook & Tanenhaus, 2009) and is found only in gesture (i.e., it is not conveyed in accompanying speech, Goldin-Meadow, 2003; Stevanoni & Salmon, 2005). We ask here what cognitive consequences these action gestures have, not for listeners, but for the gesturers themselves.

Research suggests that how we act influences how we think by grounding our perception, affect, and even language comprehension in the sensorimotor systems used to interact with the world (Barsalou, 1999; Beilock et al., 2008; Niedenthal, 2007; Glenberg & Robertson, 2000; 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., our 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 et al., 2002; Wilson & Knoblich, 2005). Hostetter and Alibali (2008) hypothesize that gesture is an explicit expression of this action simulation. We take this hypothesis one step further. We suggest that gesture is not only a vehicle for expressing action information, but, because it is itself action, gesture can add action information to the gesturer's mental representations. In simulating our own internal thoughts, gesture thus ties them to action in a way that speech does not.

In two experiments, participants performed the Tower of Hanoi task (TOH; Newell & Simon, 1972; Fig.1,top) where the goal is to move disks, arranged largest-disk on bottom to smallest-disk on top, from one of three pegs to another peg without placing a larger disk on a smaller disk and moving only one disk at a time. Experiment-1 contained three parts: participants (1) solved the TOH problem (TOH1); (2) explained, using both speech and gesture, how they solved the problem; (3) solved it again (TOH2). For all participants, the smallest-disk in TOH1 was the lightest (0.8kg) 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 (2.9kg) in TOH2 and, because it was so heavy, could only be lifted with two hands.

Participants could use either one-handed or two-handed gestures to represent moving the smallest (and lightest disk) in their explanations of TOH1.

But note that, for the *Switch Group*, one-handed gestures are 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 *Switch Group* participants' mental representation would not be compatible with the TOH2 task they are about to solve and they should perform worse than *No-Switch Group* participants on TOH2. If gesture really causes these group differences, then the more one-handed gestures the *Switch Group* uses to depict moving the smallest-disk, the worse their TOH2 performance.

If we are correct that gesturing is *creating* a representation of the smallest-disk tied to action (as opposed to *reflecting* an already held belief), then gesturing should be crucial to our effect. Participants who do *not* gesture between TOH1 and TOH2 should not show a decrement in performance when the disk weights are switched. Experiment-2 tests this prediction.

## EXPERIMENT-1

### *Methods*

#### *Participants*

Participants (*No-Switch Group*:N=12; *Switch Group*:N=14) were recruited for a study examining “object manipulation.” We were interested in how people learned to solve the TOH task. Pilot testing revealed that when participants initially solved TOH1 in <65 seconds, they had little room to improve (i.e., it was impossible to test for learning). Therefore, to explore the impact of our

experimental manipulations on TOH learning, only participants who solved TOH1 in >65 seconds were included.

### *Procedure*

All participants gave informed consent and were tested individually. Participants first solved four practice trials of TOH. 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 that participants would encounter on the trials of interest. For all practice trials, disk size correlated with weight (Fig.1,top). After each practice trial, participants were asked to explain to the experimenter how they solved the problem and 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 to compare performance on the TOH task after the weight of the disks was manipulated.

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

Finally, all participants returned to the first room where they again solved a four-disk TOH problem (TOH2). Some participants solved the same version of TOH they had solved originally (*No-Switch Group*). Other participants solved a reversed version (*Switch Group*). Here, the smallest-disk was the heaviest and

the largest-disk the lightest. Importantly, when the smallest-disk weighed the least, it could be lifted with *one-hand*. But when it weighed the most, the smallest-disk was too heavy to be lifted with one hand and needed *two-hands* to be lifted successfully. In all other respects, TOH2 switched disks looked identical to the unswitched disks, and 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;seconds) was our main performance measure.<sup>1</sup> This measure was highly correlated with the difference in number of moves used to solve the task [ $r=.80, p<.0001$ ].

Changing the weights of the disks for TOH2 had a significant impact on performance. As expected, practice improved performance for the *No-Switch Group*, the group for whom the disk weights were unchanged (Fig.2,right,blue). The *No-Switch Group* solved TOH2 in less time than TOH1 [ $M=-1.7, SE=12.9$  sec]. In contrast, the *Switch Group* took longer to solve TOH2 than TOH1 [ $M=2.8, SE=8.9$ sec] (Fig.2,right,red). Change in performance from TOH1 to TOH2 was dependent on whether the weights of the disks had changed—a task(TOH1,TOH2) x group(*No-Switch,Switch*) interaction [ $F(1,24)=5.05, p<.04$ ].

Why did changing disk weights influence TOH performance? Importantly, 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 used to move the disks.<sup>2</sup> Disk weight

was, however, often reflected in gesture, and the particular gestures used when explaining TOH1 had an impact on TOH2.

When the *Switch* and *No-Switch Groups* explained how they solved TOH1 (where the smallest-disk was lightest), some participants in both groups used one-hand gestures while talking about how they moved the smallest-disk (Fig.1,bottom,left); others used two-hand 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-hand gestures that the *Switch Group* 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.

We found that the more incompatible gestures the *Switch Group* produced—that is, the more these participants gestured about moving the smallest-disk with one-hand—the longer they took to solve TOH2 relative to TOH1 [ $r = .55, p < .05$ ; Fig.3,right]. For the *No-Switch Group*, there was no relation between percentage of one-hand gestures and change in performance from TOH1 to TOH2 [ $r = -.37, p > .23$ ; Fig.3,left].

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 be reflecting participants' previous action experience. But this was not the case. Differences in the *Switch* and *No-Switch Groups'* performance across TOH attempts (i.e., TOH2–TOH1sec) did not depend on the percentage of one-hand *actions* participants used to move the smallest-disk when solving TOH1 [no

Group x Hand-Movement interaction,  $p > .1$ ). Performance differences across TOH attempts for the *Switch* and *No-Switch Groups* were dependent only on the percentage of one-hand gestures used to describe the smallest-disk—a Group x Hand-Gesture interaction [ $\beta = 1.15, t = 2.19, p < .04, \text{Fig. 3}$ ]. This interaction remained significant even when the number of hands used to act on the smallest-disk during TOH1 was used as a covariate in the gesture analysis [ $\beta = 1.13, t = 2.08, p < .05$ ].

Importantly, *Switch Group* participants are not just taking 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 smallest-disk gestures, the more moves *Switch Group* participants took to solve TOH2 relative to TOH1 [ $r = .75, p < .01$ ]. This was not the case in 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 eventually encountered when solving TOH2 (the smallest-disk was now 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* reflects nothing more than an encoding specificity effect (Tulving & Thompson, 1973), where 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, reflecting different problem-solving strategies. Moreover, if we restrict our sample to only those who solved TOH1 and TOH2 differently, a task x group interaction in problem-solving time remains significant [ $F(1,19)=4.57, p<.05$ ; to be consistent with previous analyses, we covaried out one-handed TOH1 actions here].

There is, however, another possibility: participants' gestures could be *reflecting*, rather than *creating*, their representation of the smallest-disk as a light object. We designed Experiment-2 to test this hypothesis. 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 Experiment-2 *Switch Group* participants, who have produced no gestures, should not show a decrement in TOH2 performance.

## EXPERIMENT-2

*Participants*

Participants (*No-Switch Group*:N=11; *Switch Group*:N=9) were recruited using the same procedures as Experiment-1.

*Procedure*

The procedure was identical to 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 in Experiment-1.

Although it might have been more straightforward to ask Experiment-2 participants to do the explanation without gesturing, pilot testing revealed that asking participants not to gesture disrupted their ability to explain TOH. People routinely gesture when talking about solving TOH (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 condition without gesture to the explanation condition with gesture in Experiment-1.

*Results and Discussion*

All Experiment-2 participants, both *Switch* and *Non-Switch Groups*, solved TOH2 faster than TOH1 [M=-13.6, SE=10.3 sec; Fig.2,left]. There was no effect of reversing disk weights on performance—no group(*No-Switch,Switch*) x task(TOH1, TOH2) interaction [F=0].

### *General Discussion*

Gestures communicate (Beattie & Shovelton, 1999; Cassell et al., 1999; Goldin-Meadow & Sandhofer, 1999). But, as we show here, they can do more. Gesturing adds action information to our mental representation of the tasks we explain. If this added information is compatible with the actions required to complete the task, subsequent performance improves. If the added information is incompatible, performance is hindered. Importantly, 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.

Gestures thus not only reflect simulated action accompanying one's mental representations (Hostetter & Alibali, 2008), gestures 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 disk weight in the explanations and the tendency to mention smallest-disk size (which is correlated with weight in TOH1) was unrelated to one-handed smallest-disk gestures in both *Switch* [ $r = -.43, p > .1$ ] and *No-Switch* [ $r = .11, p > .7$ ] groups. Smallest-disk size mentions were also unrelated to performance across TOH attempts (i.e., TOH2-TOH1sec; *Switch*:  $r = -.10, p > .7$ ; *No-Switch*:  $r = -.28, p > .3$ ).

Recent work by Cook and Tanenhaus (2009) demonstrates that watching another's gestures can have an impact on the watcher's subsequent

performance. Participants watched spontaneous gestures that either mimicked the way TOH disks are lifted, or that traced the trajectory of the disks. All watchers then solved TOH on a computer. The group that saw gestures mimicking actual movements was more likely to make the computer disks follow real-world trajectories (i.e., they took the disks up and over the peg). The other group was 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 show that one's *own* gestures can have an impact on subsequent performance. Gesturing does not merely reflect thought—gesture changes thought by introducing action into our mental representations. Gesture forces us to think with our hands.

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## Footnotes

<sup>1</sup>A difference score was used for ease of interpretation. However, raw scores reveal no significant difference across groups on TOH1 [*No-Switch*, 120.9sec, SE=12.1; *Switch*, 109.0 sec, SE=9.7;  $F < 1$ ] and a significant group difference on TOH2 [*No-Switch*, 89.2sec, SE=8.9; *Switch*, 111.8sec, SE=11.8], even when TOH1 is used as a covariate [ $F(1,23)=4.33, p < .05$ ].

<sup>2</sup>Although disk weight was not mentioned 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 small-disk size. Unlike the gesture results, there was no relation between *Switch Group* participants’ frequency of labeling the smallest-disk “small” and performance (TOH2-TOH1;  $r = -.10, p > .7$ ).

**Figure 1.** A participant performing TOH1 and using two hands to move the largest and heaviest disk from one peg to another (top); the 4 disks weighed 2.9, 2.3, 1.6, and 0.8 kg, respectively. Participants producing a one-hand (bottom left) or two-hand (bottom right) gesture while explaining how they moved the smallest disk. The explanations were produced after participants completed TOH1, when the smallest disk was the lightest and therefore movable with either one or two hands.

**Figure 2.** Difference in time (in seconds) taken to solve the TOH problem (TOH2–TOH1) for participants who, after completing TOH1, explained how they solved the task and gestured while doing so (right graph), and for participants who gave no explanations between TOH1 and TOH2 and therefore did not gesture (left graph). Explainers in the *Switch* condition showed less improvement (i.e., a more positive change score) from TOH1 to TOH2 than explainers in the *No-Switch* condition. Non-explainers showed no difference between conditions.

**Figure 3.** Difference in time (in seconds) taken to solve the TOH problem (TOH2–TOH1) as a function of the percent of one-hand gestures participants used to explain how they solved TOH1. The *Switch Group*, the group for whom the disk weights were reversed on TOH2 (so that the smallest disk became the heaviest and could no longer be lifted with one hand) showed a positive relation between percent one-hand gestures and TOH2–TOH1 performance time (right graph). The more one-hand gestures, the more time participants took to solve TOH2 relative to TOH1 (reflecting relatively poorer performance across time). The *No-Switch Group*, who used the same disks throughout, showed no relation

between the TOH2 – TOH1 time difference and percent one-hand gestures (left graph).

Figure 1



Figure 2

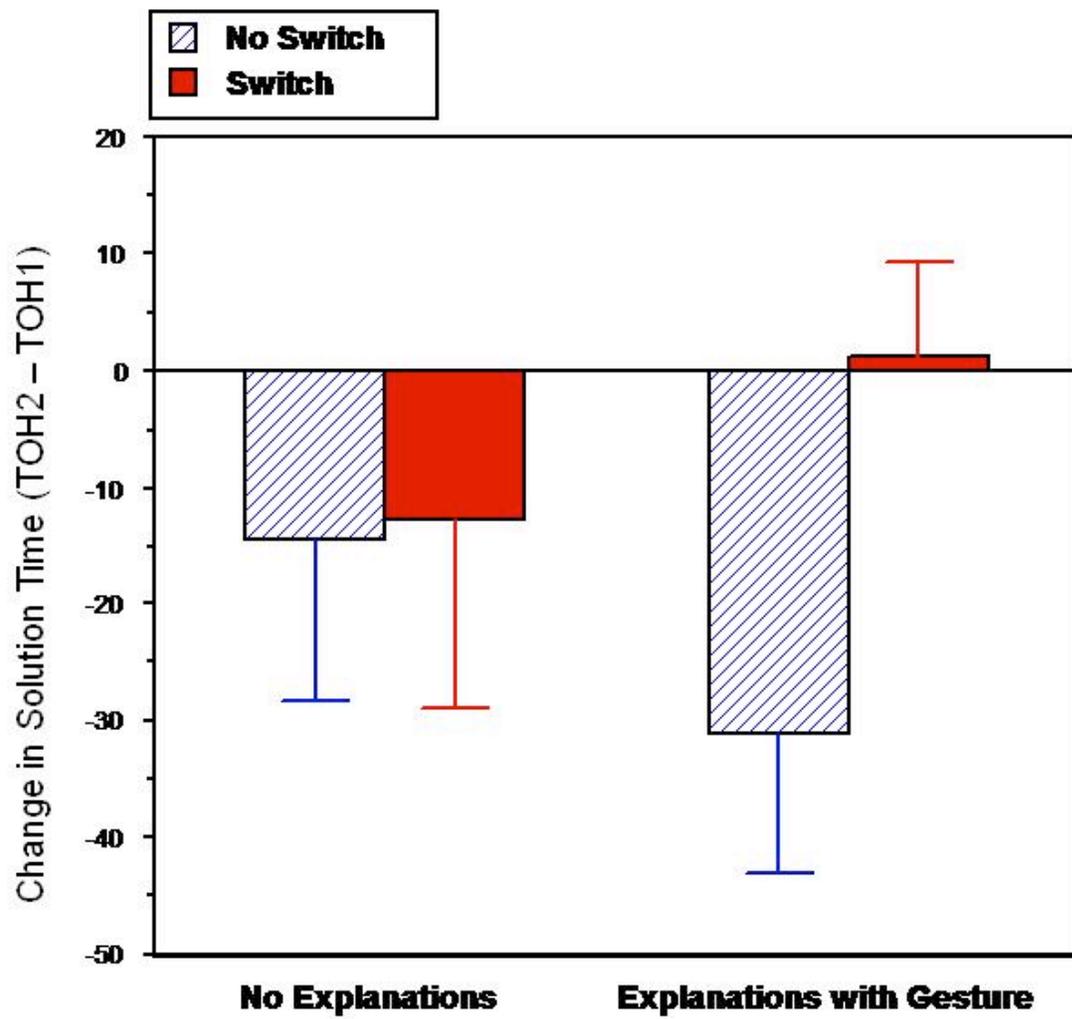


Figure 3

