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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 37(0)

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Publication Date

2015

More than Meets the Eye: Gesture Changes Thought, even without Visual Feedback

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Abstract

When speakers gesture, their gestures shape their thoughts, but *how* this happens remains unclear. What kinds of feedback from gesture—visual, proprioceptive, or both—drive these cognitive effects? Here we address this question using a test bed previously employed to explore gesture's cognitive effects (Beilock & Goldin-Meadow, 2010). Participants solved the Tower of Hanoi puzzle, explained their solutions in speech and gesture, and solved the puzzle a second time. Previous studies using this paradigm have demonstrated that the gestures participants produce during the explanation phase affect their ability to solve the problem the second time. Unlike these prior studies, however, participants in the present study were blocked from seeing their hands while they gestured. Despite this absence of visual feedback, our results replicate previous studies in which visual feedback was available. These findings suggest that gesture may shape thought through proprioceptive feedback alone.

Keywords: gesture; problem solving; Tower of Hanoi; embodied cognition

Introduction

Our thoughts shape our actions, but only recently has it become clear that the reverse is also true: our actions feed back to shape our thoughts. Motor experience changes how we perceive actions we see later on (Calise & Giese, 2006), how we learn (James & Swain, 2011) and comprehend language (Beilock et al., 2008), how we assign valence (Casasanto & Chrysikou, 2011), and even how we solve problems (Thomas & Lleras, 2009). Interestingly, however, not all actions change thought to the same degree or in the same way. One kind of action—*gesture*, produced whenever people talk and reason—has been found to have particularly strong effects on subsequent mental representations. For example, teaching children a particular gesture gives them new ideas about how to solve math problems (Goldin-Meadow et al., 2009), and encouraging adults to gesture leads them to do better on mental rotation problems (Chu & Kita, 2011). In fact, recent results suggest that gesture may be more powerful in shaping mental representation than actions performed on objects (Goldin-Meadow & Beilock, 2010; Trofatter et al. 2014), and, in particular, may be more powerful than action in promoting generalization to new types of problems (Novack, et al. 2014).

The thought-changing power of gesture has been demonstrated across several paradigms and in both children and adults, but the *source* of gesture's power remains unknown (c.f. Clark, 2013; Pouw, et al. 2014). How does gesture feed back to shape thought? Which features of gesture drive these observed effects, and which are merely incidental? One possibility is that certain types of feedback from gesture are more important than others. Gestures, like all actions, are very often both seen and felt. When we turn a knob, lift a book, or push a button, we receive both visual and proprioceptive feedback from these actions as they unfold. In the same way, when we gesture in the air to represent turning a knob, lifting a book, or pushing a button, we receive both visual and proprioceptive feedback, albeit different feedback than from action itself. Is one of these types of feedback—visual or proprioceptive—more important than the other in shaping mental representation, or are both necessary?

On the one hand, there are reasons to think that gesture's thought-changing effects may require visual feedback. Seeing other people's gestures changes thought (Singer & Goldin-Meadow, 2005), and seeing one's own may have similar effects. Adults' understanding of spoken messages is heavily influenced by the speaker's co-speech gestures (e.g., Kelly et al., 2014). For example, even when told to focus solely on the spoken message, individuals are quicker to understand that message with a congruent gesture (e.g., "She chopped onions," accompanied by a chopping gesture) than with an incongruent gesture (e.g., "She chopped onions," accompanied by a sweeping gesture). In fact, people are not just affected by qualitative properties of others' gestures, such as the handshape in the above examples, but by quantitative properties as well. For example, Cook and Tanenhaus (2009) showed that when listeners view explanations of the Tower of Hanoi puzzle, the height of the speakers' gestures influences the height of listeners' movements when they later solve the puzzle themselves. The fact that people integrate information from *others'* gestures just by seeing them provides indirect support for the possibility that visual feedback may be the route through which speakers' integrate information from their *own* gestures.

At the same time, there are reasons to think that gesture might *not* rely on visual feedback. Blind speakers gesture, even when talking to listeners they know to be blind (Iverson & Goldin-Meadow, 1998). The fact that blind individuals cannot see their gestures, but still produce them, suggests that gestures have the potential to be cognitively effective even when they are felt and not seen. Research on signers also suggests a privileged role for proprioceptive over visual feedback. Signers do not self-monitor their signs via visual feedback and may even be distracted by it (Emmorey, Bosworth, & Kraljic, 2009). In sum, although prior findings hint at the importance of both seeing and feeling gesture, it remains an open question as to whether both are required for gesture to have an effect on mental representation. Note that, importantly, it is not possible to experimentally eliminate proprioceptive feedback. Our task instead is to eliminate the visual feedback that speakers receive from their own gestures to determine whether doing so will eliminate the effects of gesture on mental representation.

To examine these questions, we turned to a paradigm—the Tower of Hanoi puzzle—that has been previously established as a test bed for understanding the cognitive effects of gesture. In a series of recent studies using the Tower of Hanoi puzzle, gesture at one phase of the paradigm has been shown to affect how people perform at a later stage of the paradigm (Beilock & Goldin-Meadow, 2010; Goldin-Meadow & Beilock, 2010; Trofatter, et al. 2014). In the paradigm, participants first solve a four-disk version of the classic Tower of Hanoi puzzle involving weighted disks and a wooden apparatus. Next, they explain how they solved the puzzle, with encouragement to gesture along with their explanations. Finally, they solve the puzzle a second time. The manipulation is in the second solution attempt. Participants in one group (the “No-Switch” group) are given the same version of the puzzle that they solved initially, whereas participants in the other group (the “Switch” group) are given a version of the puzzle in which the weights of the disks have been reversed: the smallest disk is now the heaviest, and the biggest disk is now the lightest. Previous studies using this paradigm have consistently found that, during this second solution, the performance of those in the Switch group suffers compared to the performance of those in the No-Switch group—a pattern of results we refer to as the “switch effect.” This is the basic effect, but prior studies have also used additional conditions and analyses to confirm that it is the participants’ gestures during the explanation phase that drives this switch effect. For example, the “switch effect” disappears when the explanation phase is removed altogether (Beilock & Goldin-Meadow, 2010), when the explanation phase is replaced with additional experience solving the physical puzzle (Goldin-Meadow & Beilock, 2010), and when the explanation involves demonstrating the solution with the actual disks rather than with gestures (Trofatter, et al. 2014). In all previous studies involving gesture during the explanation phase, participants gestured under natural conditions— that is, they could both see and feel their gestures and thus received visual and proprioceptive feedback from them. In the present study, participants were prevented from seeing their gestures by an opaque screen, which we call the “visual blind” (Figure 1). If participants under these “blind” conditions still show the switch effect, we can conclude that visual feedback from gesture is not necessary and perhaps that gesture shapes thought through proprioceptive feedback alone. If the switch effect disappears, we can conclude that visual feedback is critical to the previously seen effects of gesture on thought.

Method

Participants

Data from 26 participants (10 males; No-Switch group: $n = 12$; Switch group: $n = 14$) were analyzed in the present study. Participants were between the ages of 18 and 36 ($M = 21$ years), and were recruited for a puzzle-solving study. All participants gave informed consent.

Materials

Tower of Hanoi apparatus. The Tower of Hanoi (TOH) apparatus was identical to that used in previous studies. It consisted of three evenly spaced wooden pegs on a wooden base. Two identically sized sets of four smooth, white disks were created. In each set, disks were four different sizes; in one set the weights were positively correlated with the disk sizes (smallest disk is also the lightest), and in the other they were negatively correlated (smallest disk is the heaviest).

Visual Blind. A large black piece of felt was attached to a wooden frame that was sized to fit comfortably around participants’ torsos. The frame could be lowered to rest just below shoulder height, thus obstructing participants’ view of their hands while still allowing full range of movement and thus full use of gesture space (see Figure 1).

Figure 1. Participant under the visual blind.

Procedure

All participants were tested individually and sessions were videotaped. At the beginning of the session, the experimenter explained the general rules of the TOH task. Participants were told that their goal was to move the disks from one peg on the puzzle board to another peg, while following two rules. First, only one disk could be moved at a time. Second, a larger disk could never be placed on top of a smaller disk. After learning the rules, participants practiced completing a simple three-disk version of the Tower of Hanoi puzzle three times. At this stage of the session, the disk size and weights were correlated such that the smallest disk was the lightest, and the largest disk was the heaviest. After the third completion of the three-disk puzzle, the experimenter added a fourth disk and asked the participant to practice solving this puzzle using the same basic rules.

TOH1. Participants then completed the first timed solution of the four-disk puzzle (TOH1). Participants who completed the puzzle in less than 65 seconds were disqualified and did not continue. This criterion was used because previous studies using the same version of the TOH task (Beilock & Goldin-Meadow, 2010; Goldin-Meadow & Beilock, 2010) have shown that participants are at ceiling and unable to improve on the task if they solve TOH1 in less than 65 seconds. As we were interested in determining whether participants showed an improvement or decrement from TOH1 to TOH2, we used the same established criterion.

Explanation Phase. Next, participants were situated under the blind. Again, the apparatus did not restrict movement in any way, but blocked the participants' view of their own hands. They were asked to explain how they solved the four-disk puzzle to another participant (in fact, a confederate), making sure to mention each step they took and to use their hands. Participants were also told that, from the listener's perspective, the blind created a visual disconnect between head and body. The stated rationale of the set-up was that we were interested in whether this visual disconnect would interfere with the listener's ability to understand the participant's explanation of the puzzle.

TOH2. After explaining their solution to the confederate, participants completed a short demographic questionnaire and a distractor task (Visualization of Viewpoints). They then solved the four-disk puzzle a second time (TOH2). For half the participants, the four-disk puzzle was identical to the puzzle they had used during TOH1 (No-Switch group). For the other half, the weights of the disks were reversed, such that the smallest disk was now the heaviest, and the biggest disk was now the lightest (Switch group). After solving the puzzle, participants were debriefed and compensated for their time.

Coding

Movement and Gesture Coding. Participants' movements (i.e., actions used to transfer disks from one peg to another during TOH1 and TOH2) and gestures (i.e., participants' co-speech gestures during the explanation of their solutions to the confederate) were coded from video. For the movements, we coded: (1) the hand or hands used (right hand, left hand, or both hands); and (2) the disk moved (smallest, etc.). For gestures, we coded: (1) the hand or hands used (right hand, left hand, or both hands); (2) whether the gesture depicted grasping a disk or merely pointed to a location; and (3) the disk referenced (smallest, etc.) To determine whether the blind apparatus affected how participants in the present study gestured, we used these same coding criteria to recode the explanations from the original TOH study (Beilock & Goldin-Meadow, 2010) in which participants explained their solutions without a visual blind.

Speech Coding. Explanations were coded for overall length, as well as for references to the disks in speech. The explanation length was used to calculate the gesture rate (gestures/minute) in the current data and in the data from Beilock and Goldin-Meadow (2010). Each reference to one of the disks was also coded for whether or not it mentioned size (e.g. "the smallest disk").

Results

Gestures under the Blind

A comparison of the gestures during the Explanation Phase of the present study with gestures in the original study (Beilock & Goldin-Meadow, 2010) showed that the visual blind had little effect on gesture production. In the current study, we found a gesture rate of 6.46 (*SD* = 2.65) gestures per minute, which was very similar to the gesture rate in the original study, 7.35 (*SD* = 3.14). A linear regression confirmed that the study in which a person participated could not be predicted by gesture rate ($\beta = 0.89$, SE = 0.81, t = 1.10, *ns*). Similarly, the proportion of one-handed gestures produced did not differ between the current study (*M* = 0.71, *SD* = 0.37) and the original study (*M* = 0.69, *SD* = 0.37; $\beta = 0.02$, SE = 0.10, t = 0.18, *ns*). Finally, the proportion of grasping gestures (out of all gestures) was marginally higher in the current study (*M* = 0.89, *SD* = 0.15) than in the original study (*M* = 0.78, *SD* = 0.27), $\beta = 0.11$, SE = 0.06, t = 1.84, $p = 0.07$. Given these findings, any differences that we find between the Switch and No-Switch groups are not likely to be attributable to differences in how participants gestured under the blind, compared to how they gestured under more natural conditions.

Performance on the TOH puzzle

The two main measures of interest were the change in number of moves and the change in time (in seconds) between participants' first and second solution attempts (TOH2-TOH1) (see Figure 2). Whereas participants in the No-Switch condition solved TOH2 in fewer moves than TOH1 (*M* = -8.92, *SD* = 11.13), on average, participants in the Switch condition took more moves to solve TOH2 (*M* = 1.36, *SD* = 5.18). We see the same pattern for the change in solution time from TOH1 to TOH2 (No-Switch: *M* = -62.25 sec, *SD* = 59.64; Switch: *M* = 16.29 sec, *SD* = 25.60). Regression analyses revealed that both change in number of moves and change in time from TOH1 to TOH2 were predicted by condition (Moves: $\beta = 10.27$, SE = 3.32, t = 3.09, $p < 0.01$; Time: $\beta = 78.54$, SE = 17.53, t = 4.48, $p < 0.001$).

In previous studies that have employed the switch manipulation, researchers suggested that the Switch group performs poorly at TOH2 because their gestures during the Explanation Phase influence their mental representation of the task. Gesturing about the disks with either one or two hands reinforces and thus strengthens the mental

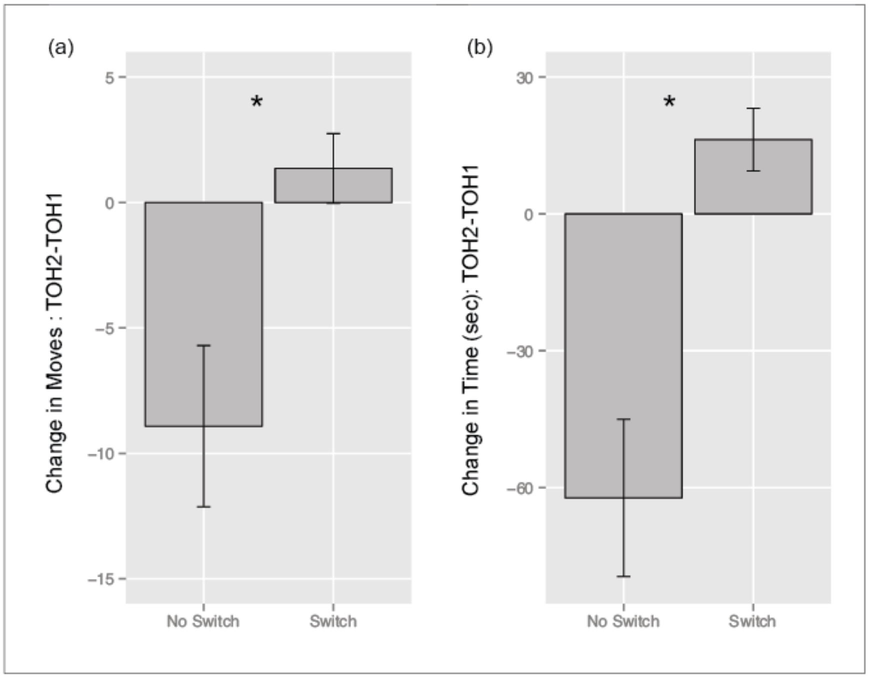

Figure 2. Change in performance between TOH1 and TOH2. (a) Change in moves (b) Change in time (sec).

representation of their weight as either relatively light or heavy. For the Switch group, strengthening the mental representation of weight highlights just the feature of the puzzle that will change in TOH2, particularly for the smallest disk. In TOH1, participants in both conditions are able to move the smallest disk with one hand; in TOH2, participants in the No-Switch group can continue to use only one hand, whereas those in the Switch group cannot because the smallest disk is now too heavy. Consistent with this interpretation, previous work has shown a significant correlation between the proportion of one-handed gestures used to represent the smallest disk during the Explanation Phase (one-handed gestures reinforce the mental representation of the disk as light) and the decrement in performance from TOH1 to TOH2. A similar analysis revealed a trend towards a significant correlation between proportion of one-handed gestures and change in moves from TOH1 to TOH2 in the Switch group in the present study ($r = 0.44$, $p = 0.11$); this correlation is non-significant in the No-Switch group ($r = -0.01$, *ns*). However, neither correlation was significant for time (Switch: $r = -0.08$, *ns*; No-Switch: $r = -0.26$, *ns*). Given the correlation between proportion of one-handed gestures and change in moves for participants in the Switch group, we suggest that, as in previous studies, the switch effect is driven by gesture's ability to influence an individual's mental representations of a task. Importantly, this effect could not be attributed to the number of one-handed moves used during TOH1 ($r = 0.002$, *ns*) or to the number of times that disk weight was mentioned in speech during the explanation ($r = 0.30$, *ns*).

Discussion

Here we investigated the mechanisms by which gesture changes mental representation. Under natural circumstances, people both see and feel their gestures. These two types of feedback—visual and proprioceptive—might both be crucial for gesture to have an effect on cognition; alternatively, one type of feedback might be more important than the other. To explore these possibilities, in the present study, we asked: Does blocking speakers from seeing their own gestures also block the effects of gesture on thought? The answer is *no*. Participants in the Switch group performed worse on the TOH puzzle after explaining it in gesture and speech, whereas participants in the No-Switch group performed better. This pattern of results replicates previous findings in which participants could see their own gestures. Visual feedback, at least in this paradigm, is not necessary for gesture to change thought.

On a cautionary note, the non-importance of visual feedback that we find in the present study could be specific to our task. When producing actions involving physical objects, people rely on different types of feedback depending on particulars of the context (Sober & Sabes, 2005), and the same may be true when producing gestures. The Tower of Hanoi puzzle is a logical problem in which the weight of the disks is irrelevant. But the way in which we designed the paradigm created a potential mismatch for participants in the Switch group between how weight is *represented* in gesture in the explanation phase and how it is later *experienced* in the second solution attempt. Indeed, this weight mismatch is what underlies the switch effect and, moreover, weight information may be better felt than seen.

Thus it is possible that, by isolating weight as the dimension along which the mismatch is experienced, we may have made proprioceptive feedback from gesture more important than visual feedback.

However, a recent study, using a different test bed for examining gesture's cognitive effects, has also found no effects of visual feedback from gesture. Brooks et al. (*under review*) studied abacus experts as they solved difficult addition problems without a physical abacus present—a technique known as mental abacus (MA). During MA, experts gesture copiously. Note that, in abacus, what matters is not the weight of the individual beads but their overall configuration in space. Visual feedback from gesture during MA might thus be expected to be critical to performance. But the researchers found no performance decrement when experts were blindfolded. Results from this study and our own thus converge on the conclusion that, whatever it is that drives gesture's cognitive effects, it is not what meets the eye.

Current evidence thus points to proprioceptive feedback as the source of gesture's cognitive effects. But this conclusion remains indirect, as, again, proprioceptive feedback cannot be manipulated experimentally in healthy adults. We may, however, gain insights from a case study that explores action and gesture in the absence of proprioception. Cole, Gallagher, and McNeill (2002) examined IW, a man who lost all proprioceptive feedback from the neck down following an illness as a young man (see also McNeill, 2005). IW taught himself to control his instrumental actions through visual feedback, but when he could not see his body, he lost control of his actions and could not move. What about gesture? Would IW be able to gesture if he were not able to see his hands? To examine this question, the researchers built a visual blind, and compared IW's ability to execute instrumental actions (such as opening a jar) with his ability to gesture while speaking (talking and gesturing about opening a jar). They found that, as expected, IW'S instrumental actions were severely compromised under the blind. However, his gestures were unaffected by the blind. This surprising result suggests that IW's gestures were guided not by visual feedback (which was blocked experimentally), and not by proprioceptive feedback (which he no longer experienced), but by some other pathway. Do IW's gestures still serve cognitive functions? We may never know given the uniqueness of IW's case, but future work using novel experimental techniques may bring us closer to an answer.

Conclusion

Gesture, like other kinds of action, has the power to shape our thoughts. In recent years, demonstrations of gesture's cognitive functions have proliferated in different paradigms and populations, but the mechanisms underlying these cognitive functions have remained mysterious. The results of the present study help to zero in on these mechanisms. When it comes to guiding action in the world, both visual and proprioceptive feedback are critical. But when it comes to the cognitive effects of a special kind of action—*gesture*—what we feel may matter more than what we see.

Acknowledgments

Funding for this study was provided by NICHD (R01-HD47450, to Goldin-Meadow) and the Spatial Intelligence and Learning Center (SBE 0541957, Goldin-Meadow is a co-PI) through the National Science Foundation. The authors would also like to thank Calla Trofatter and Cassie Sarnell for help with data collection, and Gwendolyn Sandoboe for data coding.

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