



## PAPER

# Doing gesture promotes learning a mental transformation task better than seeing gesture

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### Abstract

*Performing action has been found to have a greater impact on learning than observing action. Here we ask whether a particular type of action – the gestures that accompany talk – affect learning in a comparable way. We gave 158 6-year-old children instruction in a mental transformation task. Half the children were asked to produce a Move gesture relevant to the task; half were asked to produce a Point gesture. The children also observed the experimenter producing either a Move or Point gesture. Children who produced a Move gesture improved more than children who observed the Move gesture. Neither producing nor observing the Point gesture facilitated learning. Doing gesture promotes learning better than seeing gesture, as long as the gesture conveys information that could help solve the task.*

### Research highlights

- Performing action has been found to have a greater impact on learning than observing action.
- We asked whether a particular type of action – the gestures that accompany talk affect learning in a comparable way in 6-year-old children performing a mental transformation task.
- Children who produced a *Move* gesture improved more than children who observed the experimenter producing a *Move* gesture; neither producing nor observing a *Point* gesture facilitated learning.
- Doing gesture promotes learning better than seeing gesture, as long as the gesture conveys information that could help solve the task.

### Introduction

The role of observation versus action in learning has been a key issue in educational practice for decades (Dewey, 1938). Recent discoveries on the relation between visual and motor inputs have made this issue central in cognitive science as well (e.g. Gallese, Fogassi & Rizzolatti, 1996). Our goal in this paper is to explore the impact that observing vs. performing an action has on learning to mentally transform spatial information. We focus on a particular type of action – the gestures speakers produce when they talk – because gesture has the potential to play a unique role in learning. Gestures

involve movements of the hand and therefore are clearly motor acts. However, gestures do not have a direct effect on the world the way most actions do – instead, gestures are representational and can thus highlight components of an action that are relevant to the task while de-emphasizing the components that are not relevant. For example, a throwing gesture may represent only the velocity and the arc of a launched object, while the act of throwing an object involves multiple physical ‘affordances’ (Gibson, 1977) between the physical characteristics of the objects (weight, shape, size, etc.) and the hand and body. Gesture’s emphasis on key aspects of the act may be particularly beneficial to learning a task. Here we investigate gesture’s role in two different learning contexts – as visual input to learning (*seeing* the gestures others produce) vs. as motor input to learning (*doing* one’s own gestures).

### *The impact of seeing vs. doing an action on learning*

Recent studies in primate and human neurophysiology suggest that visual and motor inputs are more integrated than previously thought – that observing and performing an action are subserved by the same neurological substrate, the visuo-motor mirror neurons (e.g. Di Pellegrino, Fadiga, Fogassi, Gallese & Rizzolatti, 1992). Since mirror neurons are sensitive both to motor input (performing an action oneself) and to visual input (seeing the same action done by others), it has been argued that they form the basis for understanding the intentions and goals

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of other actors (Rizzolatti & Craighero, 2004). The argument goes as follows: when we perform an action, we experience a particular intentional state, accompanied by a pattern of neurological activation; this pattern of neurological activation is similar to the activation we experience when we observe others performing the same action; we therefore attribute our intentional state to others.

But what if we have never performed the particular action ourselves? What if it is a novel act? Sommerville, Woodward and Needham (2005) have shown that young infants need to perform a novel, goal-directed action themselves before they can attribute the intent to perform goal-directed actions to others. Sommerville and colleagues gave 3-month-old infants, who are limited in both their perception and production of goal-directed actions, Velcro-covered 'sticky mittens' that allowed them to apprehend objects by swiping at them. Infants who wore the mittens were able to act on objects in relatively organized ways, looking at the object while aiming swipes toward it; in other words, they could produce goal-directed reaching actions of their own. In turn, these infants were more likely to view others' reaching actions as goal-directed than infants who were not given experience with the sticky mittens. Extending these observations, Gerson and Woodward (2011) gave one group of infants experience watching an adult produce actions with sticky mittens (the *seeing* condition) according to a script based on the actions produced by another group of infants who had used the mittens (the *doing* condition). The yoked design meant that infants in the *seeing* condition received the same levels of experience with the relevant actions as infants in the *doing* condition. Nevertheless, it was only infants in the *doing* condition, and not those in the *seeing* condition, who profited from the experience and began to perceive others' reaching actions as goal-directed.

Although it may be essential for 3-month-old children to perform goal-directed actions of their own in order to attribute goal-directed intentions to another, at some point in development children are able to learn novel behaviors from observing others (e.g. Gergely, Bekkering & Kiraly, 2002). However, this ability takes time to emerge. For example, Provasi, Dubon and Bloch (2001) compared 9- and 12-month-old infants' ability to learn the relation between a movement and an effect through action vs. observation. The infants were given three similar toys, each with a single unique lever that could be manipulated to reveal a hidden toy. Infants in the action condition were allowed to freely explore each of the toys in succession; infants in the observation condition watched the experimenter demonstrate how to manipulate the lever on each toy to reveal the hidden toy. The 12-month-old infants learned from observing the experimenter and, in fact, infants in the observation condition produced more target acts than infants in the action condition. In contrast, the 9-month-olds learned little from observing the experimenter and learned only from

acting on the toys themselves. Elsner (2007) has hypothesized that children must be able to encode both the movement and its effect in order to learn novel actions from observation. By 18 months, children have acquired this skill and no longer need to be given full demonstrations in order to learn movement-effect relations from observation. At this age, children can reproduce action effects even after observing an adult's unsuccessful attempt; for example, an adult tries to open an object but fails, thus modeling an imperfect movement without the effect; the child nevertheless performs the actions needed to produce the desired effect (Bellagamba & Tomasello, 1999; Meltzoff, 1995).

Gesture is akin to an unsuccessful attempt in that the effect of the movement instantiated in the gesture is not displayed. But gestures are different from unsuccessful attempts in that they *represent* actions and, in this sense, might be difficult for children to exploit in a learning situation, be they self-produced or produced by another.

### *Gesture's role in learning*

Gesture is, in general, a unique interface between the motor system and more abstract representations. It can convey information that is strategic to solving the task and is stripped of the sensory-motor constraints of a fully realized action (including constraints imposed by the outcome of the action), while still being rooted in the motor system (Beilock & Goldin-Meadow, 2010; Cook & Tanenhaus, 2009; Goldin-Meadow & Beilock, 2010; Hotstetter & Alibali, 2008, 2010). Gesture has been shown to play a key role in learning a variety of tasks, both seeing the gestures of others (Singer & Goldin-Meadow, 2005; Ping & Goldin-Meadow, 2008) and doing one's own gestures (Broaders, Cook, Mitchell, and Goldin-Meadow (2008); Cook, Mitchell & Goldin-Meadow, 2008; Goldin-Meadow, Cook & Mitchell, 2009). However, to our knowledge, no one has yet examined whether producing one's own gesture has the same impact on learning as seeing another produce that same gesture.

We address this question with respect to mental rotation, which is a classic task that requires visuo-spatial simulation or 'mental emulation' (Shepard & Metzler, 1971; Moulton & Kosslyn, 2009). In a mental rotation task, a participant is asked to decide whether two shapes are the same or different. There is a dependency between the angle at which one of the shapes is rotated and the time it takes the participant to decide whether it is the same or different from the other shape (Shepard & Metzler, 1971). We have chosen to use the mental rotation task in our study for several reasons. First, a number of studies have shown links between mental rotation tasks and motor processes (e.g. Ganis, Keenan, Kosslyn & Pascual-Leone, 2000; Kosslyn, 1990; Vingerhoets, de Lange, Vandemaele, Deblaere & Achten, 2002; Wexler, Kosslyn & Berthoz, 1998). For example, in behavioral studies, physically rotating a dial in one direction interferes with mentally

rotating the dial in the opposite direction (Wexler *et al.*, 1998). In imaging studies, mental rotation tasks activate premotor areas responsive to planning and processing actions (Vingerhoets *et al.*, 2002). Moreover, a single-pulse TMS (transcranial magnetic stimulation) to the left primary motor cortex makes participants process a mental rotation task more slowly, suggesting that motor cortex plays a causal role in processing mental imagery (Ganis *et al.*, 2000). Second, both adults and children gesture when solving (Chu & Kita, 2011) or explaining how they solved (Chu & Kita, 2008; Ehrlich, Levine & Goldin-Meadow, 2006) mental rotation tasks. Finally, although mental rotation tasks can be simplified for young children (Levine, Huttenlocher, Taylor & Langrock, 1999), many 5-year-olds have difficulty solving these simplified problems correctly and thus could benefit from effective instructional strategies.

The goal of our study is to explore the impact that *seeing* vs. *doing* a gesture has on improving mental rotation skill. If gesture's influence on learning stems, at least in part, from the fact that it is grounded in action (Goldin-Meadow & Beilock, 2010; Hofstetter & Alibali, 2008), we might expect that *doing* a gesture relevant to the task would facilitate learning better than *seeing* someone else produce that gesture. However, if it is only the more abstract aspects of gesture that are important for learning, there may not be a substantial difference on this task between *doing* vs. *seeing* the gesture. We explore these possibilities in a training study with 6-year-old children using the mental transformation task developed by Levine *et al.* (1999).

## Method

### Participants

One hundred and fifty-eight 6-year-old children ( $M = 73.6$  months,  $SD = 0.40$ ; range: 52–90 months, 75 girls) participated in the study, which was conducted in pre-schools in the greater Chicago area. All children's parents had submitted written consent prior to children's participation in the study.

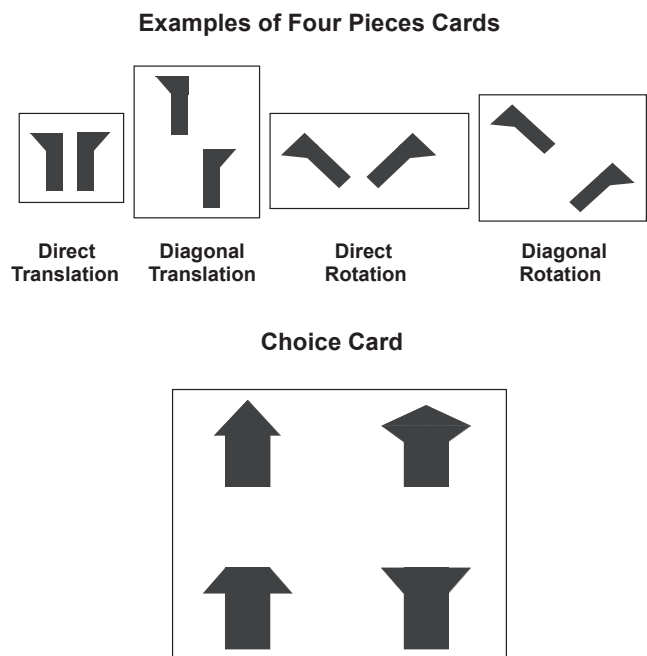
### Materials and stimuli

Participants were given 18 pretest items, six training items, and 18 different posttest items. They were asked to explain their answers to the last six items of the pretest and the posttest; the gestures they produced on the pretest explanations gave us a baseline measure of the gestures the children produced on problems of this type. The pretest and posttest stimuli were identical to those used in Ehrlich *et al.* (2006). Each problem had a 'pieces card' (containing two identical pieces that could be slid and/or rotated to form a target shape) and a 'choice card' (containing the target and three foils). Children had to mentally manipulate the two pieces on the card to

determine which of the four shapes on the choice card was the target. The location of the target was pseudo-randomized across trials so that it did not appear in the same location for more than two consecutive trials.

Half of the problems were symmetrical along a horizontal axis; half were symmetrical along the vertical axis. There were four different types of problem differing in the type of spatial transformation needed to create the target shape (see Figure 1): (1) Direct Translation, where pieces had to be moved perpendicular to the line of symmetry to create the target shape; (2) Diagonal Translation, where pieces had to be moved diagonally to create the target shape; (3) Direct Rotation, where pieces had to be rotated at a 45 degree angle and then moved perpendicular to the symmetry line to create the target shape; and (4) Diagonal Rotation, where pieces had to be rotated at 45 degrees and then moved diagonally to create the target shape. In half of the Diagonal Translation and Diagonal Rotation problems, the piece on the left was higher than the piece on the right; in half, the piece on the right was higher than the piece on the left.

The four types of problems were counter-balanced across participants, using two different order sequences. There were three instances of each of the four types of problems in the first 12 problems on the pretest and posttest (i.e. three Direct Translation, three Diagonal Translation, three Direct Rotation, and three Diagonal Rotation). The last six problems, which the children were asked to explain, consisted of one Direct Translation, two Diagonal Translation, two Direct Rotation, and one



**Figure 1** Examples of four different pieces cards, each illustrating a different spatial transformation, and the choice card that would be presented with each of the pieces cards. The shape in the bottom right corner is the target for all four pieces cards.

Diagonal Rotation problems. During training, all children were given six problems in the same order, one Direct Translation, two Diagonal Translation, one Direct Rotation, and two Diagonal Rotation problems.

### *Design and procedure*

All testing was video recorded with consent of the children's parents. After being randomly assigned to one of four experimental intervention conditions, each child was given the pretest by the first experimenter. On problems 13 through 18, children were asked to explain how they got the answer to each problem. Children were then trained by a second experimenter, who demonstrated how to solve one problem and then presented another problem for the child to solve. Experimenter and child alternated in this fashion for the six training problems. The experimenter always indicated the correct target during her turn, but gave the child no feedback during the child's turn. After the training period, the first experimenter returned and administered the posttest.

### Pretest and posttest

The pieces card and its choice card were simultaneously placed on the table in front of the child, with the pieces card closest to the child. On the first trial, the experimenter said the following: 'Look at the pieces' (while pointing at the pieces card). 'Now look at the shapes' (while pointing at the choice card). 'If you put these pieces (point at pieces card) together they will make one of these shapes (point at choice card). Point to the shape that the pieces make.' No feedback was given on any item.

### Training conditions

Our goal was to compare the effect that doing vs. seeing a relevant gesture would have on learning. To meet this goal, we needed to give children an opportunity to both produce and observe a gesture relevant to the mental transformation task. We chose a *Move* gesture that mimicked the movement needed to reorient the two items on the pieces card so that they would form the correct shape on the choice card; although produced without speech in our manipulations, this movement is one that children often produce along with speech in the gestures they spontaneously use when describing how they solved mental transformation problems of this type (Ehrlich *et al.*, 2006). The experimenter either performed the *Move* gesture (holding two flat hands over the two items on the pieces card and mimicking the movement needed to transform the pieces into one of the shapes on the choice card) or asked children to perform the *Move* gesture themselves ('Show me with your hands how to move the pieces together to make one of these shapes'). In order to assess whether learning was affected by seeing or producing a particular gesture (as opposed to seeing

or producing any movement at all), half of the children saw the experimenter produce a *Point* gesture at the two items on the pieces card (indicating the two items on the pieces card with two flat hands), and half were asked by the experimenter to produce a *Point* gesture themselves ('Point to the pieces'). We thus had four conditions varying with respect to the type of gesture produced (*Move* vs. *Point*) and who produced it (*Experimenter* vs. *Child*): Experimenter *Move*/Child *Move* ( $n = 38$ ), Experimenter *Move*/Child *Point* ( $n = 40$ ), Experimenter *Point*/Child *Move* ( $n = 40$ ), Experimenter *Point*/Child *Point* ( $n = 40$ ). Table 1 displays the instructions used in each of the four conditions, with the instructions that differed across conditions in bold italics.

### Coding the pretest explanations

We transcribed the gestures and speech the children produced during the explanations they gave on the last six pretest problems. We coded a gesture as a *Move* when the child moved her hands in a straight or curved line representing bringing the pieces together (showing either that one piece can be moved toward the other, or that the two can be moved toward each other); children tended to use pointing handshapes in these gestures, but also used flat or C-shaped hands. We coded speech as a *Move* if the child talked about connecting or moving the pieces together (e.g. 'Because if you put them together, it makes an X.' 'Because if you connect them together, it will make that shape.' 'Push them together like that, it kind of makes like that.' 'They connect together and then they made it.').

For each child, we calculated the total number of problems solved correctly on the first 12 problems (which were counter-balanced by type) on the pretest and posttest. We also calculated for each child the total number of problems (out of the six pretest problems on which explanations were given) that contained a *Move* explanation in gesture and the total number that contained a *Move* explanation in speech.

## Results

### *Pretest*

We first examined the children's performance on the pretest to determine whether there were initial differences among children who were randomly assigned to the four training conditions.<sup>1</sup> We found that children in the Experimenter *Move*/Child *Move* condition solved 5.05 ( $SD = 2.57$ ) problems correctly (out of 12) on the pretest, children in the Experimenter *Move*/Child *Point*

<sup>1</sup> We found no differences across conditions in the number of pretest problems solved correctly for the two orders of presentation; results were therefore collapsed across the two orders,  $F(1, 622) = 1.59$ ,  $p = .21$ .



**Table 1** Instructions given on the six training problems to children in each of the four conditions. Instructions that varied across condition are in bold italics*1. Experimenter Move/Child Move:*

'If these two pieces are moved together (**while producing a Move gesture with two flat hands over the two items on the pieces card**), they will make one of these shapes (points at the choice card). **Show me with your hands how to move the pieces together to make one of these shapes.** Now, point to the shape the pieces make.'

*2. Experimenter Move/Child Point:*

'If these two pieces are moved together (**while producing a Move gesture with two flat hands over the two items on the pieces card**), they will make one of these shapes (points at the choice card). **Point to the pieces.** Now, point to the shape the pieces make.'

*3. Experimenter Point/Child Move:*

'If these two pieces are moved together (**while pointing to the two items on the pieces card with two flat hands**), they will make one of these shapes (points at the choice card). **Show me with your hands how to move the pieces together to make one of these shapes.** Now, point to the shape the pieces make.'

*4. Experimenter Point/Child Point:*

'If these two pieces are moved together (**while pointing to the two items on the pieces card with two flat hands**), they will make one of these shapes (points at the choice card). **Point to the pieces.** Now, point to the shape the pieces make.'

condition solved 5.75 ( $SD = 2.15$ ), children in the Experimenter Point/Child Move condition solved 5.23 ( $SD = 2.34$ ), and children in the Experimenter Point/-Child Point condition solved 5.28 ( $SD = 2.66$ ). An ANOVA on pretest scores with two between-subjects factors, Type of Experimenter Gesture (Move, Point) and Type of Child Gesture (Move, Point) showed no significant effects of Experimenter Gesture,  $F < 1$ , or Child Gesture,  $F(1, 623) = 1.24$ ,  $p = .26$ , and no significant interaction,  $F(1, 623) = 1.83$ ,  $p = .18$ .<sup>2</sup>

We also examined performance on the four different types of transformation problems. We found that there were reliable differences among types of problems on the pretest (out of a possible 3): Direct Translation  $M = 1.19$  ( $SD = 0.90$ ), Diagonal Translation  $M = 1.34$  ( $SD = 0.92$ ), Direct Rotation  $M = 1.51$  ( $SD = 0.93$ ), Diagonal Rotation  $M = 1.26$  ( $SD = 0.84$ ),  $F(3, 623) = 3.78$ ,  $p < .05$ . Post-hoc comparisons using Tukey's Honestly Significant Differences revealed that children performed better on Direct Rotation problems than on Direct Translation problems,  $p < .01$ ; no other differences were significant, all  $ps > .05$ . This pattern is unexpected given that rotation problems are typically more difficult for children of this age than translation problems (Levine *et al.*, 1999).

Unlike Ehrlich *et al.* (2006) who found sex differences on pretest scores on the same mental transformation task, we found no differences between girls ( $M = 5.24$ ,  $SD = 2.44$ ) and boys ( $M = 5.37$ ,  $SD = 2.43$ ) on the pretest,  $F < 1$ , possibly because the children in our study came from lower SES homes where sex differences in spatial skills are not always found (Levine, Vasilyeva, Lourenco, Newcombe & Huttenlocher, 2005).

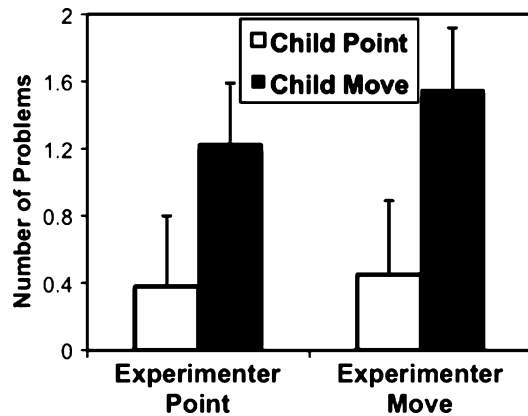
Finally, we examined children's explanations on the last six pretest problems, and found no differences in the number of *Move* explanations that the four groups produced in speech on these problems: Experimenter Move/Child Move,  $M = 2.97$ ,  $SD = 2.05$ ;

Experimenter Move/Child Point,  $M = 2.59$ ,  $SD = 2.15$ ; Experimenter Point/Child Move,  $M = 3.61$ ,  $SD = 1.98$ ; Experimenter Point/Child Point,  $M = 3.17$ ,  $SD = 2.38$ . An analysis of variance showed no significant differences in the *Move* explanations children produced in speech on the pretest as a function of assignment to the Child *Point* vs. *Move* groups,  $F(1, 154) = 1.99$ ,  $p = .16$ , or to the Experimenter *Point* vs. *Move* groups,  $F(1, 154) = 2.31$ ,  $p = .13$ , and no interaction,  $F < 1$ . Even though the number of *Move* explanations produced in gesture on these pretest problems was highly correlated with the number of *Move* explanations produced in speech,  $r = .74$ ,  $p < .001$ , we did find pretest differences across the groups in the number of *Move* explanations the children produced in gesture: Experimenter Move/Child Move,  $M = 3.81$ ,  $SD = 1.97$ ; Experimenter Move/Child Point,  $M = 2.76$ ,  $SD = 2.02$ ; Experimenter Point/Child Move,  $M = 4.11$ ,  $SD = 1.89$ ; Experimenter Point/Child Point,  $M = 3.31$ ,  $SD = 2.29$ . The number of *Move* gestures produced by children randomly assigned to the Child *Move* groups ( $M = 3.76$ ,  $SD = 2.06$ ) differed significantly from those produced by children assigned to the Child *Point* groups ( $M = 2.76$ ,  $SD = 2.23$ ),  $F(1, 154) = 8.29$ ,  $p < .01$ , but the number of *Move* gestures produced by children assigned to the Experimenter *Move* groups did not differ significantly from those produced by children assigned to the Experimenter *Point* groups,  $F(1, 154) = 1.18$ ,  $p = .28$ ; there was no interaction between factors,  $F < 1$ . To control for these differences, we used the number of pretest problems on which children produced *Move* explanations in gesture and (for completeness) the number of problems on which children produced *Move* explanations in speech as covariates in our analyses of improvement after training.

*Improvement from pretest to posttest after training*

Figure 2 presents our central finding – that the mean number of problems on which children improved from pretest to posttest depended on type of child gesture, not type of experimenter gesture. Using an ANCOVA with two between-subjects factors, we found a significant

<sup>2</sup> We also found no significant differences across groups when we calculated number correct based on all 18 pretest problems: 7.95 ( $SD = 3.74$ ), 8.95 ( $SD = 2.77$ ), 8.43 ( $SD = 3.23$ ), 8.35 ( $SD = 3.78$ ), all  $Fs < 1$ .



**Figure 2** Improvement from pretest to posttest. The figure displays the mean number of problems on which children in the four conditions improved after training. Error bars are standard errors.

effect of Type of Child Gesture,  $F(1, 622) = 7.31, p < .01$ , but no effect of Type of Experimenter Gesture,  $F < 1$ , and no interaction,  $F < 1$ . Although all of the groups improved, children improved most when they themselves produced a *Move* gesture during training (black bars in Figure 2), regardless of whether the Experimenter produced a *Point* or *Move* gesture (white bars). Importantly, there were no significant effects of our pretest explanation measures on improvement, either the number of *Move* explanations produced in gesture,  $F < 1$ , or the number of *Move* explanations produced in speech,  $F < 1$ .<sup>3</sup>

We also examined how much improvement children made on the four different types of transformation problems and found no statistically significant differences across problem types,  $F(3, 622) = 2.13, p = .10$ : Direct Translation ( $M = .34, SD = 1.06$ ), Diagonal Translation ( $M = .30, SD = 1.18$ ), Direct Rotation ( $M = .21, SD = 1.13$ ), Diagonal Rotation ( $M = .04, SD = 1.17$ ).

Finally, we found no significant differences in improvement from pretest to posttest comparing girls ( $M = 0.15, SD = 1.14$ ) and boys ( $M = 0.29, SD = 1.13$ ),  $F < 1$ , and no significant interaction with problem type,  $F < 1$ .<sup>4</sup>

<sup>3</sup> Neither pretest covariate correlated with our outcome measure: *Move* in gesture at pretest and improvement after training:  $r = .01, p = .93$ , *Move* in speech at pretest and improvement after training:  $r = -.09, p = .28$ .

<sup>4</sup> Importantly, we find precisely the same pattern of results if we calculate improvement after training based on all 18 problems (including the six on which the child gave explanations). We found a significant effect of Type of Child Gesture,  $F(1, 622) = 12.45, p < .000$ , no effect of Type of Experimenter Gesture,  $F < 1$ , no interaction,  $F < 1$ , and no effect of either pretest covariate, *Move* in gesture,  $F < 1$ , *Move* in speech,  $F(1, 622) = 2.09, p = .15$ . The difference across problem types is again significant,  $F(3, 622) = 3.07, p < .05$ , and there are no sex differences or interactions, all  $F_s < 1$

## Discussion

We have found that children asked to produce a *Move* gesture during instruction on a mental transformation task profited from that instruction, and did so significantly more than children asked to produce a *Point* gesture. Our results thus demonstrate that self-produced gesture can play a role in learning, as long as the gesture highlights relevant aspects of the task (in this case, the path along which the pieces can be moved to form a shape) and does not just engage the child in motor activity.<sup>5</sup> However, our results do not allow us to rule out the possibility that practice is what led children in the *Move* gesture condition to improve after instruction, and that children in the *Point* gesture condition improved less because the pointing gesture interfered with learning. If so, note that our data still demonstrate the importance of producing one's own gesture, as the experimenter's *Point* gesture did not interfere with learning. Indeed, the different gestures that the experimenter produced had absolutely no effect on learning at all – children asked to produce a *Move* gesture during instruction profited from the instruction whether the experimenter produced a *Move* or a *Point* gesture, and children asked to produce a *Point* gesture profited less whether the experimenter produced a *Move* or a *Point* gesture. Instruction to produce a *Move* gesture thus did not serve merely to highlight relevant aspects of the task, as the experimenter's *Move* gesture indicated the same aspects of the task as the child's *Move* gesture. Our results thus provide evidence that the child's own gestures are integral to the learning effect.

Experience doing an activity has been shown in previous work to have an impact on the way in which the activity is subsequently processed. For example, Calvo-Merino, Glaser, Grezes, Passingham and Haggard (2005) used functional magnetic resonance imaging (fMRI) to study brain activation patterns when individuals watched an action in which they were skilled, compared to one in which they were not skilled. Experts in classical ballet or Capoeira (a Brazilian art form that combines elements of dance and martial arts) watched videos of the two activities while their brains were being scanned. Brain activity when individuals watched their own dance style was compared to brain activity when they watched the other unfamiliar dance style (e.g. ballet dancers watching ballet versus ballet dancers watching Capoeira). Greater activation was found when experts viewed the familiar vs. the unfamiliar activity in a network of brain regions

<sup>5</sup> It is possible that the experimenter telling the child to 'show me with your hands how to move the pieces together to make one of these shapes' (rather than the child producing the movement) focused the child on the correct solution to the problem and led to greater learning. However, it is important to point out that in the study conducted by Ehrlich *et al.* (2006), one group of children was told to imagine moving the pieces together and this type of training was no more effective than practice without any instruction at all.

found in previous work to support both the observation and production of action (e.g. bilateral activation in premotor cortex and intraparietal sulcus, right superior parietal lobe, and left posterior superior temporal sulcus; Rizzolatti, Fogassi & Gallese, 2001).

The important finding from the point of view of our study is that these activation effects are found for individuals who have had experience *doing* the activity, and are not found for individuals who have only had experience *seeing* the activity. In a clever follow-up study, Calvo-Merino, Grezes, Glaser, Passingham and Haggard (2006) examined brain activation in male and female ballet dancers. Each gender performs several moves not performed by the other gender. But because male and female ballet dancers train together, they have extensive experience seeing (although not doing) the other gender's moves. Calvo-Merino and colleagues found greater premotor, parietal, and cerebellar activity when dancers viewed moves they themselves performed, compared to moves the opposite gender performs. Having had experience *doing* an action influenced how that action was subsequently processed in ways that *seeing* the action did not.

We see similar effects for children in learning situations. For example, James (2010) used fMRI to compare brain activation patterns in preliterate children before and after they were taught letters. One group practiced printing letters during the learning phase; the other group practiced recognizing letters. In addition to finding an overall left-hemisphere bias during letter perception, James (2010) found enhanced activation in the visual association cortex – but only for children who practiced printing the letters, not for children who practiced recognizing the letters. Similarly, James and Swain (2011) taught young children words for actions, each performed on a different object. One group actively manipulated the objects during the training period; the other group watched the experimenter manipulate the objects. The motor system, as demonstrated by the children's brain activation patterns using fMRI, was recruited when children listened to the words they had learned – but only in children who performed the actions themselves, not in children who observed the actions performed. These studies suggest that 'learning-by-doing' can lay the foundation for neural systems underlying a variety of skills, and can lead to recruiting the motor system even when actions are not involved in the task. The fact that, in our study, gesturing during instruction resulted in improved performance on the mental transformation task leads us to suggest that learning-by-gesturing may serve the same function.

Another way in which gesturing could have had an impact on learning how to mentally transform spatial stimuli in our study is through its effect on memory. Acting out phrases has been found to facilitate recall of those phrases (Cohen, 1987; Engelkamp, Zimmer, Mohr & Sellen, 1994; Mulligan & Hornstein, 2003). Similarly, producing gestures when describing a series of video-

taped events can facilitate recall of the events (Cook, Yip, and Goldin-Meadow, 2010). Moreover, the effect that gesturing has on memory is long-lasting; gesturing when describing the videotaped events improved recall not only immediately after encoding the events, but also three weeks later (Cook *et al.*, 2010). Gesture's long-lived effect even extends to learning situations – children who gesture while learning a new mathematical concept maintain what they have learned better than those who do not gesture while learning (Cook *et al.*, 2008), as do adults who gesture while learning sentences in a foreign language (Allen, 1995). Gesturing, like acting, appears to be important in constructing new representations that last over time.

A third way in which gesturing could have had an effect on learning in our study is by guiding the learner's search for perceptual information. Olson (1970) suggested that performatory acts provide occasions for elaborating and revising perceptual information. In his view, it is in the context of performatory attempts, such as drawing, that alternatives arise; these alternatives then propel the search for additional perceptual information. Gesturing is a different type of performatory act, as it does not have a direct effect on objects in the world and it does not leave a residue. It is interesting, then, that in the context of the mental transformation task, the act of gesturing has an impact on learning and that doing one's own gesturing has a larger impact than watching someone else produce the same gesture. Under Olson's (1970) view, the difference stems from the fact that different perceptual cues are picked up when doing a gesture than when seeing a gesture.

Related to Olson's view (1970), gesturing may have had its effect on learning how to mentally transform spatial stimuli by focusing the learner's attention on the task. Children's attention may be more engaged (or differently engaged) on a problem when they are asked to move their hands than when they are asked to watch others move their hands. Using eye-tracking to examine where children are looking during instruction would allow us to take the first step in testing this hypothesis: Are patterns of attention different when children produce their own gestures than when they observe someone else gesture?

We have shown that gesture can function like action in that producing a gesture has a greater impact on learning than seeing someone else produce the gesture. A question for future research is whether doing the action itself would be even more effective in facilitating learning than doing a gesture that represents the action. If learning is promoted by simulating action, we might expect learning to be optimal when the entire action underlying the task (including the outcome, which is not portrayed in a gesture) is invoked during the learning process. Acting out a task should then be more likely to promote success on the task than gesturing about the task. Alternatively, learning may be bogged down by potentially irrelevant details involved in acting on the world. If so, gesturing



about a task could promote learning (and perhaps promote generalization) more effectively than acting out the task precisely because gesture involves only core components of the actual action. Moreover, unlike acting, when gesturing learners must mentally represent the results of their movements. Doing so could encourage the learner to imagine those results, which might be particularly important in a task such as mental rotation. To explore the effect that action vs. gesture has on learning, we will need to manipulate whether children perform an action (e.g. rotating an object) or a gesture for that action (e.g. gesturing *rotate*) during training, and observe the effect of that manipulation on learning. Our future work will explore this question.

In sum, we have found that doing a particular gesture has a bigger effect on learning than seeing that gesture, a finding that parallels research on doing vs. seeing action (e.g. Gerson & Woodward, 2011). Children asked to produce a gesture during instruction on a mental transformation task profited from that instruction more than children asked to watch someone else perform the gesture. Moreover, it is not merely self-produced activity *per se* that promotes learning on a mental rotation task – to be effective, the gesture must contain information that is relevant to solving the task. Our findings thus pave the way for using gesture in educational settings to enhance spatial learning, particularly in situations where performing the actions represented by gesture would be difficult or impossible.

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## References

- Allen, L.Q. (1995). The effects of emblematic gestures on the development and access of mental representations of French expressions. *Modern Language Journal*, **79** (4), 521–529.
- Beilock, S.L., & Goldin-Meadow, S. (2010). Gesture grounds thought in action. *Psychological Science*, **21**, 1605–1610.
- Bellagamba, F., & Tomasello, M. (1999). Re-enacting intended acts: comparing 12- and 18-month-olds. *Infant Behavior and Development*, **22** (2), 277–282.
- Broaders, S., Cook, S.W., Mitchell, Z., & Goldin-Meadow, S. (2007). Making children gesture brings out implicit knowledge and leads to learning. *Journal of Experimental Psychology: General*, **136** (4), 539–550.
- Calvo-Merino, B., Glaser, D.E., Grezes, J., Passingham, R.E., & Haggard, P. (2005). Action observation and acquired motor skills: an fMRI study with expert dancers. *Cerebral Cortex*, **15**, 1243–1249.
- Calvo-Merino, B., Grezes, J., Glaser, D.E., Passingham, R.E., & Haggard, P. (2006). Seeing or doing? Influence of visual and motor familiarity on action observation. *Current Biology*, **16**, 1905–1910.
- Chu, M., & Kita, S. (2008). Spontaneous gestures during mental rotation tasks: insights into the microdevelopment of the motor strategy. *Journal of Experimental Psychology: General*, **137** (4), 706–723.
- Chu, M., & Kita, S. (2011). The nature of gestures' beneficial role in spatial problem solving. *Journal of Experimental Psychology: General*, **140**, 102–116.
- Cohen, R.L. (1987). Interevent differences in event memory: why are some events more recallable than others? *Memory & Cognition*, **15** (2), 109–118.
- Cook, S.W., Mitchell, Z., & Goldin-Meadow, S. (2008). Gesturing makes learning last. *Cognition*, **106**, 1047–1058.
- Cook, S.W., & Tanenhaus, M.K. (2009). Embodied communication: speakers' gestures affect listeners' actions. *Cognition*, **113**, 98–104.
- Cook, S.W., Yip, T., & Goldin-Meadow, S. (2010). Gesturing makes memories last. *Journal of Memory and Language*, **63** (4), 465–475.
- Dewey, J. (1938). *Experience and education*. New York: Collier Books.
- di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: a neurophysiological study. *Experimental Brain Research*, **91** (1), 176–180.
- Ehrlich, S.B., Levine, S.C., & Goldin-Meadow, S. (2006). The importance of gesture in children's spatial reasoning. *Developmental Psychology*, **42**, 1259–1268.
- Elsner, B. (2007). Infants' imitation of goal-directed actions: the role of movements and action effects. *Acta Psychologica*, **124**, 44–59.
- Engelkamp, J., Zimmer, H.D., Mohr, G., & Sellen, O. (1994). Memory of self-performed tasks: self-performing during recognition. *Memory & Cognition*, **22** (1), 34–39.
- Gallese, V., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain*, **119**, 593–609.
- Ganis, G., Keenan, J., Kosslyn, S., & Pascual-Leone, A. (2000). Transcranial magnetic stimulation of primary motor cortex affects mental rotation. *Cerebral Cortex*, **10** (2), 175–180.
- Gergely, G., Bekkering, H., & Kiraly, I. (2002). Rational imitation in preverbal infants. *Nature*, **415**, 755.
- Gerson, S., & Woodward, A.L. (2011). What's in a mitten? The effects of active versus passive experience on the origins of intention understanding. (Under review)
- Gibson, J.J. (1977). The theory of affordances. In R. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing: Toward an ecological psychology* (pp. 67–82). Hillsdale, NJ: Lawrence Erlbaum.
- Goldin-Meadow, S., & Beilock, S.L. (2010). Action's influence on thought: the case of gesture. *Perspectives on Psychological Science*, **5**, 664–674.
- Goldin-Meadow, S., Cook, S.W., & Mitchell, Z.A. (2009). Gesturing gives children new ideas about math. *Psychological Science*, **20** (3), 267–272.
- Hostetter, A.B., & Alibali, M.W. (2008). Visible embodiment: gestures as simulated action. *Psychonomic Bulletin and Review*, **15**, 495–514.
- Hostetter, A.B., & Alibali, M.W. (2010). Language, gesture, action! A test of the gesture as simulated action framework. *Journal of Memory and Language*, **63**, 245–257.



- James, K.H. (2010). Sensori-motor experience leads to changes in visual processing in the developing brain. *Developmental Science*, **13** (2), 279–288.
- James, K.H., & Swain, S.N. (2011). Only self-generated actions create sensori-motor systems in the developing brain. *Developmental Science*, **14**, 1–6.
- Kosslyn, S.M. (1990). Mental imagery. In D.N. Osherson, S.M. Kosslyn & J.M. Hollerbach (Eds.), *An invitation to cognitive science: Visual cognition and action* (Vol. 2, pp. 267–296). Cambridge, MA: MIT Press.
- Levine, S.C., Huttenlocher, J., Taylor, A., & Langrock, A. (1999). Early sex differences in spatial skill. *Developmental Psychology*, **35**, 940–949.
- Levine, S.C., Vasilyeva, M., Lourenco, S.F., Newcombe, N.S., & Huttenlocher, J. (2005). Socioeconomic status modifies the sex difference in spatial skill. *Psychological Science*, **16** (11), 841–845.
- Meltzoff, A. (1995). Understanding the intentions of others: reenactment of intended acts by 18-month-old children. *Developmental Psychology*, **31** (5), 838–850.
- Moulton, S.T., & Kosslyn, S. (2009). Imagining predictions: mental imagery as mental emulation. *Philosophical Transactions of the Royal Society B-Biological Sciences*, **364**, 1273–1280.
- Mulligan, N.W., & Hornstein, S.L. (2003). Memory for actions: self-performed tasks and the reenactment effect. *Memory & Cognition*, **31** (3), 412–421.
- Olson, D.R. (1970). *Cognitive development: The child's acquisition of diagonality*. New York: Academic Press.
- Ping, R., & Goldin-Meadow, S. (2008). Hands in the air: using ungrounded iconic gestures to teach children conservation of quantity. *Developmental Psychology*, **44**, 1277–1287.
- Provasi, J., Dubon, C.D., & Bloch, H. (2001). Do 9- and 12-month-olds learn means–ends relation by observing? *Infant Behavior and Development*, **24**, 195–213.
- Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience*, **27**, 169–192.
- Rizzolatti, G., Fogassi, L., & Gallese V. (2001). Neurophysiological mechanisms underlying understanding and imitation of action. *Nature Reviews Neuroscience*, **2**, 661–670.
- Shepard, R.N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, **171**, 701–703.
- Singer, M.A., & Goldin-Meadow, S. (2005). Children learn when their teachers' gestures and speech differ. *Psychological Science*, **16**, 85–89.
- Sommerville, J.A., Woodward, A.L., & Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. *Cognition*, **96**, B1–B11.
- Vingerhoets, G., de Lange, F.P., Vandemaele, P., Deblaere, K., & Achten, E. (2002). Motor imagery in mental rotation: an fMRI study. *NeuroImage*, **17**, 1623–1633.
- Wexler, M., Kosslyn, S.M., & Berthoz A. (1998). *Motor processes in mental rotation*. *Cognition*, **68** (1), 77–94.

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