Producing gestures facilitates encoding of spatial relation

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Abstract

This paper examines whether producing gestures would facilitate encoding of spatial relation in a navigation task. In this experiment, we focused on gestures produced without accompanying speech. Adult participants were asked to study spatial sequence of routes shown in four diagrams, one at a time. Participants rehearsed the routes with gestures, actual hand movements (actually drew the routes on papers), or mental simulation. They then were asked to reconstruct the routes with sticks. Participants who moved their hands (either in the form of gestures or actual drawing) recalled better than those who mentally simulated the routes and those who did not rehearse, suggesting that hand movements produced during rehearsal facilitate encoding of spatial relation. Interestingly, participants who gestured the routes in the air recalled better than those who drew them on papers, suggesting that gesture, as a kind of representational action, exerts more powerful influence on spatial relation encoding.

Keywords: Gesture; Spatial Cognition; Action; Encoding; Embodied Cognition.

Introduction

Spatial knowledge consists of three major skills, including spatial visualization, spatial relation, and spatial orientation (Lohman, 1979). The present study focuses on *spatial relation*. Understanding relational information enables us to form a spatial representation regarding relation between locations, objects, and paths. Such understanding is particularly useful when we are processing spatial information of how starting points and destinations are considered in relation to one another. Therefore, developing techniques to facilitate encoding of spatial relation has received increasing attention from cognitive and educational psychologists all over the world.

In the present study, we examine whether embodied movements like *gestures* might be effective in encoding spatial relation. Previous research has shown that producing gestures is directly involved in encoding new information but those studies focused on mathematics domain. Children who were told to gesture when explaining their solutions to a math problem benefited more from the subsequent math lesson, compared to children who were told not to gesture (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007). Children who were instructed to reproduce teacher's gestures while acquiring new mathematics concepts learnt and memorized mathematics knowledge better than did those who were instructed to reproduce teacher's verbal instructions only (Cook, Mitchell, & Goldin-Meadow, 2008). However, no experimental work has examined whether gestures strengthen spatial relation encoding. Gestures are spontaneous hand movements. They are produced in space, and thus are inherently spatial (McNeill, 1992; 2005). Therefore, learners can exploit the spatial properties of gestures to encode spatial relation between the starting point and destination. For example, when encoding spatial sequence of a route, learners may trace the steps with an index finger in the air by moving it to the right, upwards, and to the right again.

In fact, gestures and spatial relation are tightly linked. Previous studies have shown that speakers produce co-speech gestures (gestures that are co-occurring with speech) when they convey spatial relation to listeners in speech. For example, they use co-speech gestures to depict spatial layout of an area (Emmorey, Tversky & Taylor, 2000) and spatial arrangement of objects (Sauter, Uttal, Alman, Goldin-Meadow, & Levine, 2012). In addition, previous studies have reported that speakers produce co-speech gestures frequently when they are identifying spatial relation between two characters in narratives (So, Coppola, Liccidarello, & Goldin-Meadow, 2005; So, Kita, & Goldin-Meadow, 2009). They also increase gesture production when encountering difficulty in describing complex spatial patterns (Hostetter, Alibali, & Kita, 2007; Melinger & Kita, 2007).

The present study asks whether asking participants to produce gestures while encoding spatial relation information would enhance subsequent spatial recall. We here focus on gestures produced while thinking silently (i.e., co-thought gestures, see Chu & Kita, 2011). If co-thought gestures merely depict spatial relation, then participants who are told to gesture when rehearsing spatial sequence silently should recall comparable number of steps than those who are told not to gesture. However, if co-thought gestures do more than simply conveying spatial relation, i.e., they are involved in encoding and constructing spatial relation, then participants who are told to gesture during rehearsal should recall more steps than those who are told not to gesture.

In order to test the above hypotheses, adult participants were told to study various routes and to rehearse the routes by producing co-thought gestures (e.g., index finger moves up and then to the right). We then compared their recall performance to another three groups of learners who were instructed, respectively, to rehearse the routes by actually drawing them out on papers, to mentally rehearse the routes while having their hand movements prohibited, and to read letters that prevented rehearsal.

Method

Participants

One hundred and twelve Chinese-speaking undergraduates (53 men, age range: 19-21 years) were recruited and each of them was paid for HKD$30 for their participation. All of them had correct or correct-to-normal vision. All but one participant were right-handed. They were undergraduates at the Chinese University of Hong Kong. The participants were randomly assigned to one of the four experimental conditions: 1) co-thought gesture; 2) actual drawing; 3) hand movement prohibited; and 4) no rehearsal, with 28 participants in each condition.

Stimuli

We designed the stimuli that purposefully examined spatial relation. Four diagrams were created by the software "Edraw Max". In each diagram, there were seven vertical lines and ten strokes that were horizontal, diagonal, or curly connecting or not connecting with the vertical lines. The strokes that were connected to vertical lines formed a route navigating from the starting point to the destination. See Figure 1 for one of the diagrams (top) and its route highlighted in red (bottom). For the sequence of this route, one should move down, then move diagonally downwards, move up, move to the right, move down, move to the right, move down, cross the curly road, move up, move diagonally upwards, move down, cross the bridge, and finally move to the destination. There were thirteen steps in each route.

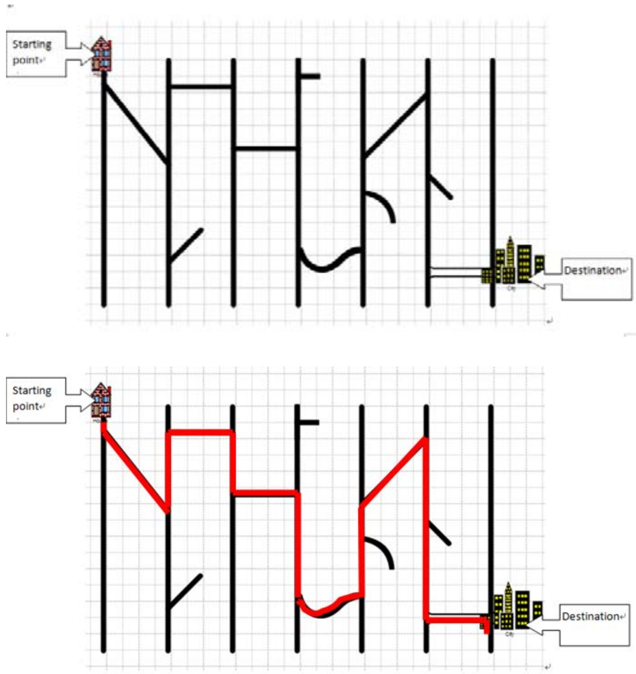

Figure 1. The top figure shows one of the maps tested in this experiment. The bottom figure shows the route navigating from the starting point to the destination.

Procedure

Participants were tested individually. They were asked to study four routes, one at a time, and later on describe the routes to an experimenter. Each time they were presented with a diagram that showed a complete route on an A4-sized paper (see the bottom figure in Figure 1). In order to help them to get familiar with the steps, participants were told to trace the complete route twice with a highlighter. They should trace every step and not to pause at any junctions of the route. Then we removed the diagram.

Participants then received different instructions for rehearsal in different conditions. In the co-thought gesture condition, participants were told to rehearse the route from the starting point to the destination with their hands. In the actual drawing condition, participants were instructed to draw the route from the starting point to the destination once on a piece of blank A4-sized paper. Participants were told that they were not required to draw the route in the same scale as that shown in the previous diagram. They were also told that neatness of their drawing would not be evaluated. In the hand movement prohibited condition, participants were told to visualize or mentally simulate the route sequence from the starting point to the destination once while holding a softball in both hands. Then they informed the experimenter when they finished visualizing a complete route. In the no rehearsal condition, participants were given an A4-sized paper with different alphabets randomly printed on it. They were told to read the alphabets aloud for 20 seconds in order to prevent them from mentally rehearsing the route. Before this experiment, we conducted a pilot study and found that on average participants spent 20 seconds on rehearsing a complete route in the hand movement prohibited condition. Therefore, we asked participants to read letters aloud for 20 seconds. We also expected that reading letters aloud would not interfere with participants' spatial representations because the letters were randomly printed on an A4-sized paper such that they did not form any clear spatial pattern.

Then all participants recalled the route they had just rehearsed. They were given thirteen sticks with the same length and told to reconstruct the route sequence from the starting point to the destination on a table. They were told that they were not required to reconstruct the route in the same scale as that shown in the diagrams.

Before they studied the second route, participants were required to work on a set of mathematics problems for two minutes in order to prevent proactive interference of the directions from the previous route. Then the second diagram was presented and the aforementioned procedures were repeated. The experiment was complete after all four routes were studied. The order of diagrams was randomized across participants. The whole experiment was videotaped.

Coding

We measured the average amount of time (in seconds) each participant spent on rehearsing a complete route (including pauses and self-corrections, if any) across four diagrams in different conditions (except the no rehearsal condition). We also examined the mean number of steps participants rehearsed in the co-thought gesture and actual drawing conditions.

We then assessed the accuracy of recall by considering how many steps (out of thirteen) were correctly reconstructed by sticks for each diagram. A step was considered recalled correctly if the direction and sequence of the corresponding stick matched those in the diagram. The mean proportion of steps correctly recalled in each diagram was calculated for each participant, which was the number of steps correctly recalled, divided by thirteen (i.e., the total number of steps in the diagram). We also measured the average amount of time (in seconds) each participant spent on reconstructing each route (including all pauses and hesitations)

Reliability was assessed by having a second coder coded a subset (20%) of the data. Inter-rater agreement was 98% (Cohen's Kappa = .95) for measuring the time spent on rehearsal; 91% (Cohen's Kappa = .88) for identifying the number of steps rehearsed in the co-thought gesture in the air, and actual drawing conditions; 95% for determining the accuracy of steps reconstructed (Cohen's Kappa = .92); and 100% for determining the duration of reconstruction (Cohen's Kappa = 1).

Results

All participants in the co-thought gesture condition gestured when they were rehearsing the routes and most of them used their index fingers. All but one participant gestured with their right hands. On average, participants in the co-thought gesture condition spent 17.86 seconds (*SD* = 2.32) to rehearse a route. Participants in the actual drawing and hand movement prohibited conditions spent 24.81 seconds (*SD* =3.14) and 19.18 seconds (*SD* = 1.19) respectively. One-way ANOVA showed that there was a significant difference in the rehearsal duration among different conditions, F (2, 82) = 12.19, p < .001. Tukey posthoc tests showed that the time spent on rehearsing a complete route in the actual drawing condition was significantly longer than that in the co-thought gesture, p < .001, and hand movements prohibited condition, p < .002. There was no difference between co-thought gesture and hand movement prohibited conditions, *ps* = ns.

The mean number of steps participants rehearsed in the co-thought gesture was 11.83 (*SD* = 3.54) and that in the actual drawing condition was 11.91 (*SD* = 5.43), t (54) = .88, ns. Thus, participants in both conditions rehearsed comparable number of steps.

We then examined the proportion of steps accurately reconstructed, which was our main interest. Figure 2 shows the mean proportion of steps correctly reconstructed in the four conditions. We conducted ANOVA with condition (co-thought gesture, actual drawing, hand movement prohibited, no rehearsal) as the between-subject independent variable and the proportion of steps correctly reconstructed as the dependent variable.

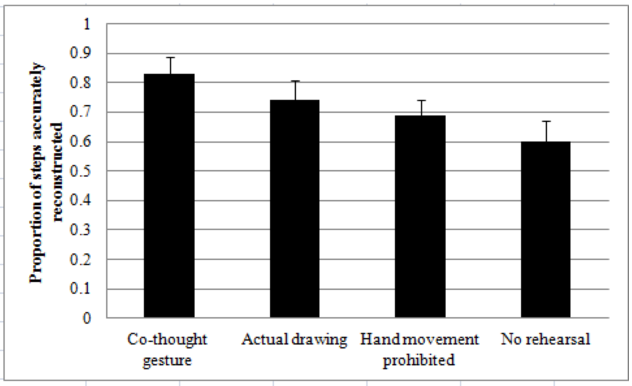

Figure 2. The mean proportion of steps correctly recalled in the co-thought gesture, actual drawing, hand movement prohibited and no rehearsal conditions.

There was a significant effect of condition, F (3, 107) = 12.81, p < .001, η^2 = .35. Planned contrasts using Bonferroni correction showed the proportion of steps correctly reconstructed in the co-thought gesture condition was higher than that in the actual drawing condition, p < .001, that in the hand movement prohibited condition, p < .001, and that in the no rehearsal condition, p < .001. The proportion of steps correctly reconstructed in the actual drawing condition was also higher than that in the hand movement prohibited condition, p < .04, and that in the no rehearsal condition, p < .001. Participants in the hand movement prohibited condition reconstructed more steps than those in the no rehearsal condition, p < .02.

On average, participants spent comparable amount of time (in seconds) in reconstructing a route in all conditions: 28.32 seconds (*SD* = 3.51) in the co-thought gesture in the air condition; 29.48 seconds (*SD* = 3.19) in the actual drawing condition; 28.38 seconds (*SD* = 3.29) in the hand movement prohibited condition; and 30.26 seconds (*SD* = 3.41) in the no rehearsal condition, *F* (3, 107) = .89, *ns*. Therefore, the greater reconstruction accuracy in the co-thought gesture conditions was not attributed to the time spent on recall.

Discussion

To summarize, participants who were instructed to gesture reconstructed more steps than those who were told to mentally rehearse the routes and those who did not rehearse the routes at all, suggesting that producing co-thought gestures during rehearsal facilitates encoding of spatial relation. Besides gesturing, drawing the routes on a paper also yielded better spatial recall than mentally rehearsing the routes. Therefore, hand movements produced during rehearsal, either in the forms of gestures or actual drawing, enhance spatial relation encoding, which in turn promote subsequent recall.

There are very few studies to date that show the role of gesture in encoding spatial relation or spatial learning in general, despite the fact that gesture itself is spatial in nature (McNeill, 1992) and it often represents visuo-spatial information (e.g., Alibali, 2005; Lavergne & Kimura, 1987; McNeill, 1992; Kita & Özyürek, 2003; So, Coppola, Liccardello, Goldin-Meadow, 2005). Of a few studies, Chu and Kita (2011) found beneficial roles of co-thought gestures in mental rotation task; Ehrlich, Levine, and Goldin-Meadow (2006) reported that frequency of co-speech gestures is positively associated with children's performance in the mental rotation task. The findings in the present study contribute to the field of gesture research in a way that producing co-thought gestures while encoding spatial information of route sequence increases recall accuracy.

Our findings converge with the embodied viewpoint of cognition. According to the theories of embodied cognition, our bodily actions are interconnected with mental representation of objects and events (e.g., Barsalou, 1999; Glenberg, 1997; Wilson, 2002). However, most of the previous studies that supported the theories of embodied cognition focused on actions on *real objects*. For example, Beilock, Lyons, Mattarella-Micke, Nausbaum, & Small (2008) found that expert ice-hockey players understood hockey-language scenarios better than did hockey novices, suggesting that previous action experience facilitates the comprehension of action-related language. Casasanto and Dijkstra (2010) also reported that participants who were told to move marbles upward retrieved positive memories more often and faster than did those who moved marbles downward, suggesting a causal link between bodily action and cognition. Previous research has also shown that actual movements improved spatial skills. For example, Weidenbauer, Schmid, and Jansen-Osmann (2007) found that participants who were trained to use a joystick to rotate two-dimensional figures had better performance in the mental rotation task than did those who were not trained. Similarly, Wexler, Kosslyn, and Berthoz (1998) showed that participants who were required to turn a joystick while solving the mental rotation task had faster response rate and higher accuracy when the direction of hand movements was congruent with the direction of mental rotation than when it was not congruent. Our findings provide additional support to the theories of embodied cognition by demonstrating that actual movements like drawing routes on papers facilitate encoding of spatial relation. However, we here take a step further and find that representational actions, i.e., gestures, produced during rehearsal also exert significant influence on encoding and retention of spatial information. Hence, embodied movements, both real and representational, would influence our spatial cognition.

In addition, although it was not part of our prediction, our findings showed that participants in the co-thought gesture condition had better recall than those in the actual drawing condition. Participants who gestured the routes recalled more steps than did those who drew them on paper. As a result, co-thought gestures seem to bring a greater impact on encoding and retaining spatial relation than actually drawing on paper. The better performance in the co-thought gesture condition, as compared to the actual drawing condition, might indicate that less concrete actions provided a greater cognitive benefit in reinforcing the spatial representation. It is possibly because producing co-thought gestures might solidify the spatial information better than drawing on paper. In the actual drawing condition, participants could see the route sequences drawn on paper and they might rely on those sequences for the rehearsal of the subsequent steps. As such, it was not necessary for them to maintain the steps actively in their memory. In contrast, participants in the co-thought gesture condition did not leave visible trails. Hence, they might have to keep rehearsing the previous steps in order to proceed to the subsequent ones. As a result, producing co-thought gestures would help participants to maintain and create a richer mental representation of the path than drawing on paper. The findings might advance our understanding about the effects of different kinds of embodied movements on spatial learning. While embodied movements in general enhance spatial relation encoding, representational movements (i.e., gestures) seem to be more effective than actual movements in improving encoding and retrieval of the path information.

However, one might contend that drawing was also involved in facilitating encoding of spatial relation in the co-thought gesture condition. This is because participants in this condition traced the complete paths twice while studying the routes before they produced co-thought gestures during rehearsal. Hence, their recall performance might be attributed to dual encoding of spatial relation by drawing and gesturing (Paivio, 1971). In contrast, participants in the actual drawing condition seemed to repeat what they were doing (i.e., drawing on papers) when they were learning and rehearsing the routes. However, participants did see the complete routes on papers while they were tracing the routes on papers whereas they did not see those routes during rehearsal. As a result, although participants drew on papers when learning and rehearsing the routes, they might use different mental processes to encode spatial relation.

While our results provide strong evidence that co-thought gestures play a causal role in encoding spatial relation, they do not tell us how gesture is involved in the encoding process. We propose that co-thought gestures can facilitate encoding of spatial sequence in various ways. First, they provide participants with rich sensori-motor representation of the sequence of steps (Hegarty, Mayer, Kriz, & Keehner, 2005; Hostetter & Alibali, 2008). In addition, they help participants to maintain the representation active in memory (de Ruiter, 1998; Wesp, Hesse, Keutmann, & Wheaton, 2001). They also help participants to offload intermediate representations of the spatial sequence to their hands in order to reduce the chance of forgetting those representations (Chu & Kita, 2011; Goldin-Meadow, Nasbaum, Kelly, & Wagner, 2001).

To our knowledge, this study is the first one to test the hypothesis that co-thought gesture is more powerful than actual movement in facilitating spatial relation encoding. Producing co-thought gestures allows us to construct the spatial information and retain it in our memory with relatively little effort. Further research should also address whether gestural encoding can be applied to other spatial tasks and how long its mnemonic effect lasts for. Based on the findings in this study, however, we could start practicing moving our fingers in the air when we are learning a direction in a new environment.

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