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Author
So, Wing Chee

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Simulating a route with your index finger: Effect of mental rehearsal on spatial memory

Wing Chee So (PSYSWC@Nus.Edu.Sg)
Department of Psychology, 9 Arts Link
National University of Singapore

Abstract

This paper examines which rehearsal method (physical practice vs. mental practice) can better strengthen spatial memory. Participants were asked to learn four routes that navigated from starting points to destinations in four different maps. Then they were asked to rehearse the routes by using one of the following methods: 1) mental practice by simulating the routes in their mind; 2) physical practice by drawing the routes on papers; 3) physical practice by having index fingers trace the routes in air with eyes closed; and 4) physically practice by having index fingers trace the routes in air with eyes open. Finally, they verbally recalled the routes. The findings showed that physical practice with index fingers tracing the routes in air while keeping the eyes closed outperformed other rehearsal methods. Thus, tracing directions in air without any visual inputs can help participants to retain the visuo-spatial memory.

Keywords: Spatial memory; Rehearsal methods; Mental simulation; Navigation; Mental representation

Introduction

"After you turn left, you go straight and turn right". When navigating from one place to another in a new environment, we have to find the route, learn the direction, and retain it in our visuo-spatial working memory (VSWM). VSWM is specialized for processing and retaining visual and spatial information (Baddeley & Logie, 1999; Logie, 1995). However, maintenance of visual and spatial information requires rehearsal process. The question of interest is what type of rehearsal method can better strengthen VSWM.

One way to rehearse spatial and visual information is to simulate the route in our mental representation, i.e., mental practice. Mentally represented objects and actions share similarities with the actual ones (Kosslyn, Pick, Fariello, 1974; Decety, Jeannerod, & Prablanc, 1989). Previous findings reported that mental practice strengthens memory in learning sport-related activities like dart throwing (Mendoza & Wichman, 1978; Surburg, Sultive, & Porretta, 1995). Mental practice is also found to be effective in enhancing actual performance in athletics (Jones & Stuth, 1997). When learning directions of a route, mental simulation allows us to form a visual image of geometric properties of the layout of the route (e.g., Finke, 1989; Kosslyn, 1980, Shepard & Cooper, 1982). In addition, it activates motor imagery whereby we imagine ourselves tracing the sequence of the direction in our visual imagery (e.g., Barsalou, 1999; Jeannerod, 1995; Kosslyn, Ball, & Reiser, 1978; Parsons, 1987; Shepard & Metzler, 1971). Activation of visual and motor processing can maintain visual and spatial information in working memory.

However, mental practice normally does not involve any overt body movements (Richardson, 1967). While we are simulating a route in our mind, we can draw the to-be-remembered route on a paper, i.e., physical practice. Physical practice is an external memory aid that refers to writing down the to-be-remembered information. Previous research found that participants who jogged notes recalled more information than those who did not (FrosterLee, et al., 2005). Yet there is no consensus of whether physical practice is more effective than mental practice. While Intons-Petersons and Fournier (1986) suggested that the use of physical practice resulted in higher recall of words than the use of mental practice, Dyer, Riley, and Yekovich (1979) reported the opposite pattern. Tigner (1999) argued that the combination of physical and mental practices is the best way of rehearsal. The first aim of the present study is to examine whether participants recall directions more accurately when they are performing mental practice, compared to those who are performing physical practice.

Other than drawing to-be-remembered route on a paper, we can indeed draw it in air as an alternative form of physical practice. Specifically, we can use our index fingers to trace the route in abstract space. The way we move our hands should reflect the direction of the simulated route in our mental representation (e.g., Hinton & Parsons, 1988; Jeannerod, 1988; Parsons, 1994). To some extent, these hand movements resemble gestures (hand movements that are produced spontaneously when talking). There is abundant evidence showing that gestures reflect individuals' thoughts and knowledge (Goldin-Meadow, 2003; McNeill, 1992), particularly spatial representation (Hostetter & Hopkins, 2002; Hostetter & Alibali, 2008; but see Wagner, Nusbaum, & Goldin-Meadow, 2004). Previous findings further showed that gestures not only reflect thinking but also bring out implicit knowledge from mental representation during the process of learning (Broaders, et al., 2007). According to this view, using index finger to trace in air makes mental simulation of a route explicit, thereby enhancing spatial memory. The second aim of the present study is to compare the number of directions correctly recalled when participants draw the route on a paper to that when they draw it in air.

If tracing the route in air is an effective rehearsal method, then do participants have to track the route in eye gaze when they trace it in air? We do so when we draw the route on a paper in physical practice. One the one hand, visual inputs are important in spatial perception and learning during the process of navigation (Loomis, et al., 1993). Specifically, tracing the route in air with eyes open might help participants to *visualize* the route simulated in their mental representation, and thus providing them feedbacks for altering the route. However, hand movements might be sufficient to send signals to our mind that in turn, evokes a motor image of the actual movement (Wehner, Vogt, Stadler, 1984). Indeed, visual inputs, especially those are not relevant, might cause visual interference (e.g., Logie, 1986; Quinn, 2008; Quinn & McConnell, 2006). While we are tracking the movement of our index fingers in eye gaze, other visual information (e.g., spatial layout and furniture setting of the room) might involuntarily enter our visual buffer, resulting in interference in our visual imagery. The third aim of the present study is to examine whether visual inputs play an important role in physical practice when participants trace the routes in air.

Overall, the present study examined whether different rehearsal methods facilitate spatial recall. There were four methods – 1) mental practice in which participants simulated the routes without hand movements; 2) physical practice in which participants simulated the routes and draw them on papers; 3) physical practice in which participants simulated the routes and draw them in air while keeping their eyes closed; and 4) physical practice in which participants simulated the routes and draw them in air while keeping their eyes open. The study adopted a between-subject design with types of rehearsal methods as the independent variable and number of direction recalled as the dependent variable.

To date, very few studies have been done in investigating whether mental practice and physical practice enhance performance in navigation. This research aims to examine whether participants recall directions more accurately if they are performing mental and physical practices. Theoretically, it gains insights into how spatial information is represented in our memory. Practically, the findings guide us to design educational programs that specifically help students to navigate.

Method

Participants

Sixty-two participants (half male and half female) aged 18 to 23 participated in this experiment to fulfill course requirements. They were undergraduates at National University of Singapore, Singapore. None of them had sensory problems. The participants were randomly assigned to one of the four experimental conditions. There were eighteen participants in the mental practice condition without overt hand movements (MP), thirteen participants in the physical practice condition where they drew the routes on papers (PP on papers), sixteen participants in the physical practice condition where they drew the routes in air eyes closed (PP in air with eyes closed), and fifteen participants in the physical practice condition where they drew the routes in air with eyes open (PP in air with eyes open). Of all the participants, fifty-three of them were right-handed and the rest were left-handed.

Stimuli

Four maps were created by the software "Edraw Max" (Figure 1a shows one of the maps). All the maps were placed on the grids and each of them had seven vertical lines and ten strokes (either horizontal, diagonal, curly, or double-lined) connecting or not connecting with the vertical lines. Landmarks (except those for the starting points and destinations) were not provided.

Each map featured a direct and *only* route navigating from the starting point to the destination. As shown in Figure 1b, after traveling from the starting point, one should move down, then move diagonally downwards, move up, move to right, move down, move to 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 in total thirteen steps in each map.

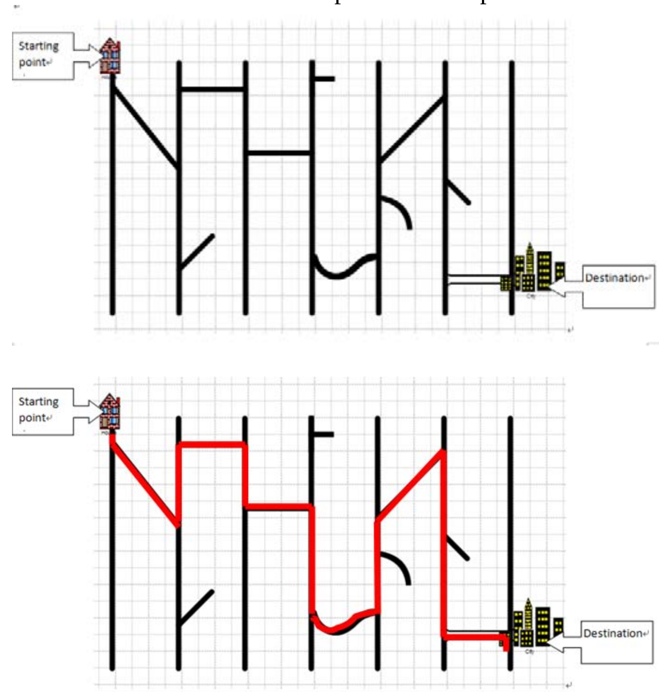

Figure 1. The top figure shows one of the maps tested in this experiment. The bottom figure shows the route navigating from the starting point to the destination.

The locations of the starting point were different across the four maps. It was situated at top left corner in Map 1, bottom right corner in Map 2, bottom left corner in Map 3, top right corner in Map 4. The destinations were situated at the opposite side of the starting points in each map.

Procedure

Participants were tested individually in each condition with four maps. The order of the maps was counterbalanced across participants. Each participant went through three phases in each condition. The whole experiment was videotaped.

The procedures in the *learning and memorizing* phase were the same in all the conditions. They were presented with a map (see Figure 1a), and asked to learn and memorize the directions of the route by tracing them with a highlighter (see Figure 1b). After the first time of drawing, a new but the same map was presented for them to draw the route for the second time. They were told to highlight every direction and not to pause at any junctions of the routes.

After finishing drawing the route of the first map, the participants entered *rehearsal* phase. The procedures in this phase were different across the conditions. Figure 2 shows what the participants did in the four conditions. In the MP condition, the participants were asked to hold a softball (hence, that their finger movements were restricted) and given 20[1] seconds to mentally rehearse the route. In the PP on paper condition, the participants were given an empty map (i.e., a map without the vertical lines and strokes) and asked to draw the routes from the starting points to the destinations. In the PP in air with eyes closed condition, the participants were asked to close their eyes and use the index fingers of their preferred hands to draw the routes in air. In the PP condition with eyes open, the participants opened their eyes while drawing the routes with their index fingers of the preferred hands in air.

Figure 2. Mental practice (MP, top left), physical practice on paper (PP on paper, top right), physical practice in air while keeping eyes closed (PP in air with eyes closed, bottom left), and physical practice in air while keeping eyes open (PP in air with eyes open, bottom right).

After the rehearsal phase, the participants were asked to describe the directions of the route from the starting point to the destination based on an aerial perspective in English to the experimenter in the *recall* phase.

After then, a second map was presented and participants were asked to learn and memorize the directions of the route, rehearse them in the respective conditions, and recall them to the experimenter. Same procedures were adopted for the third and fourth maps.

At the end of the experiment, an online Corsi Block Test was administered to examine the participants' spatial memory span (Orsini, Grossi, Capitani, Laiacona, Papagno, & Vallar, 1987). In this test, the participants viewed a black dot sequentially flashed in random squares on a computer screen, with each dot flashing approximately 1000ms. After viewing the sequence, they had to click on the squares that showed the dots in the same order. All the participants started with watching the sequences in which three dots were flashing (i.e., level 3). After they clicked the squares correctly over two consecutive trials, they progressed to the next advanced level (i.e., four dots). The task was discontinued when participants erroneously recalled the order of the visual dot sequence presentation in two consecutive trials. The most advanced level that the participants could achieve was recorded.

Scoring and coding

We recorded the duration of rehearsal for each participant by counting the number of seconds spent on rehearsing the complete route from the starting point to the destination in each map. The duration included all the pauses, hesitations, and self-corrections. We also looked at to what extent the participants rehearsed the routes accurately. For the participants in the PP on paper condition, we compared the directions and orders of the steps drawn on the papers to those on the maps. For those in the PP in air conditions, we drew the routes on papers based on the directions of their imagined hand movements followed by examining the directions and orders. A step was considered to be correctly rehearsed if its direction *and* order matched with that in the map. Steps that were not found in the maps but rehearsed (i.e., false memory) were excluded from the analyses. The participants got 1 point for each correct step but zero for a missing step and a step in which its direction and / or order was wrongly rehearsed. There were 13 steps in each map, and thus, the total point each participant could get in all the four maps was 52. Note that the mental rehearsal of the participants in the MP condition could not be evaluated due to the absence of overt hand movements.

The participants verbally described the route to the experimenter in the recall phase. All speech produced in the recall phase was transcribed by the coders who were native English speakers. Then the coders identified the steps the participants mentioned in speech and evaluated whether the directions and their orders were accurately recalled. A step was considered to be correctly recalled if its direction *and* order matched with that in the map. Steps that were not found in the maps but recalled (i.e., false memory) were excluded from the analyses. Same as the scoring procedures in the rehearsal phase, the participants got 1 point for the recall of each correct step. The total point for all the four

[1] We had run a pilot study and found that the participants spent around 20 seconds to trace a route in air.

maps was 52. We then calculated the proportion of correct directions recalled for each participant.

Reliability was assessed by having a second coder code 20% of the data. Inter-rater agreement for measuring the time spent on rehearsal was 98% (Cohen's Kappa = .96); determining the accuracy of rehearsal was 90% (Cohen's Kappa = 88); describing directions in speech was 95% (Cohen's Kappa = .91); and determining the accuracy of steps recalled was 96% (Cohen's Kappa = .94).

Results

On average, the participants recalled a sequence of six dots (*SD* = 1.19, ranging from 4 to 9 dots) in the Corsi Block Test. The individual variations in the spatial span might influence the participants' performance in our experiment. Hence, we put it as a controlled variable in all the following analyses.

Table 1 shows the average time (in seconds, *SD*) spent on different types of rehearsal and the average proportion of directions (*SD*) correctly rehearsed. The participants spent comparable amount of time on the rehearsal in the PP on papers, PP in air with eyes closed, and PP in air with eyes open conditions, $F(2, 39) = .32$, p = ns. However the accuracy of their rehearsed routes differed across the conditions, $F(2, 39) = 8.82$, $p = .001$. The proportion of directions correct rehearsed was higher in the PP in air with eyes closed than in the PP in air with eyes opened, $p = .001$. There was no significant difference between other pairs.

Table 1: Average amount of time (in seconds, SD) spent on rehearsal and proportion of directions (SD) correctly rehearsed.

Condition	Average amount of time spent (in seconds, *SD*)	Proportion of directions correctly rehearsed (*SD*)
PP on papers	107.31 (*61.55*)	.75 (*.10*)
PP in air with eyes closed	96.25 (*80.07*)	.83 (*.10*)
PP in air with eyes open	74.57 (*40.57*)	.72 (*.08*)
MP	80 (*N/A*)	N/A

Next, we looked at whether the types of rehearsal influenced spatial recall in speech. Table 2 shows the average time (in seconds, *SD*) spent on the recall and average proportion of directions (*SD*) accurately recalled in all the four conditions. The participants spent comparable amount of time on verbal recall in all the four conditions, $F(3, 55) = 2.41$, p = ns. However, the recall accuracy was different across the conditions, $F(3, 55) = 3.30$, $p = .027$. The proportion of directions correctly recalled in the PP in air with eyes closed condition was higher than that in the MP condition, $p = .04$, that in the PP on papers condition, $p = .03$, and that in the PP in air with eyes open condition, $p = .05$. There was no significant difference between other pairs.

Table 2: Average amount of time (in seconds, *SD*) spent on verbal recall and proportion of directions (*SD*) correctly recalled.

Condition	Average amount of time spent (in seconds, *SD*)	Proportion of directions correctly rehearsed (*SD*)
PP on papers	134.15 (*77.04*)	.63 (*.12*)
PP with eyes closed	140.19 (*82.26*)	.74 (*.10*)
PP with eyes open	104.29 (*28.12*)	.66 (*.08*)
MP	140.83 (*55.45*)	.64 (*.10*)

Discussion

The first aim of the present study was to examine whether participants recalled directions more accurately when they were performing mental practice, compared to those who were performing physical practice. Our findings showed that physical practice with index finger tracing the route in air with eyes closed yielded higher recall rate than mental practice. In other words, mental simulation is more effective when it is accompanied by hand movements in air than when it is not. So how do these hand movements in air strengthen memory? There are several possibilities. Tracing the route with index finger in air helps the participants to reveal the simulated route, thus making it more explicit. Moreover, it might help the participants to stay focused on the simulated image and prevent them from being lost in their mind. It might also allow the participants to maintain the simulated route active and longer before the image fades, thereby making memory traces stronger and more robust.

To some extent, tracing routes with index finger looks similar to gestures that we produce when we are talking. In fact, some participants reproduced the tracing hand movements when they were verbally recalling the route. These hand movements, which were referred to gestures as they were co-occurring with speech, might help the participants to retrieve the directions that were rehearsed earlier. Previous research found that reproducing gestures that learners have encoded earlier facilitates learning and memory recall in a variety of tasks (Cook, Mitchell, & Goldin-Meadow, 2008; Tellier, 2008).

The second aim of the present study was to compare the proportion of directions correctly recalled when participants drew the routes on papers to that when they drew them in air with eyes opened. Our findings showed that the proportion of directions recalled in these two kinds of physical practice was comparable. In other words, it does not make a difference in recall rate when participants drew the routes on papers or in air. Indeed, the proportions of directions recalled in these two kinds of physical practice were even similar to the proportion in the mental practice condition, suggesting that hand movements with eyes open were not particularly effective in enhancing memory recall. Such result was in contrary to previous findings which showed that overt hand movements can serve as an enactment and enhance memory recall (Zimmer & Englekamp, 2003). One possibility is, when keeping their eyes open, participants involuntarily processed other kinds of visual inputs that were not relevant with the spatial layout of the routes. Thus, it might cause interference in visual processes (e.g., Logie, 1986; Quinn, 2008; Quinn & McConnell, 2006). In fact, we noticed that some of the participants in the physical practice with eyes open condition chose not to look at their hands during rehearsal. Perhaps they tried to avoid processing irrelevant visual inputs.

Finally, our findings showed that hand movements in air strengthened spatial memory only when the participants kept their eyes closed. Our findings showed that the participants rehearsed and recalled better when they closed their eyes than when they opened their eyes. A prior we expected that visual feedbacks could provide the participants feedbacks of the routes they simulated. However, they might be redundant or even interfering mental simulation. Hand movements instead can send signals to the brain, which evokes the motor image and assesses the accuracy of the simulated directions (Wehner, et al., 1984). Using eye gaze to track the simulated route might add extra burden to the participants who had to process sensory and motor inputs simultaneously.

To summarize, using an index finger to trace the route in air with eyes closed was the best rehearsal method for spatial recall. We can apply this finding to educational setting where students try to remember the geographical locations of countries or recall the visual-spatial information.

The present study has two limitations. First, participants in the physical practice in air with eyes closed condition outperformed those in the mental practice condition. Such difference might not be necessarily attributed to the lack of hand movements in the mental practice condition. Rather, it can be explained by the lack of visual inputs in the physical practice condition. In the present study, most participants kept their eyes open when they were doing mental practice. However, such rehearsal method might not be effective as it might arouse visual interference. Hence, in future research, we should also compare mental practice with eyes open to that with eyes closed. Second, the rehearsal time in the mental practice condition was shorter than that in the physical practice conditions (drawing routes on papers and tracing routes in air with eyes closed). Such difference might explain why participants recalled directions less accurately in the mental practice condition. Further study should consider how rehearsal time interacts with the type of rehearsal method in memory recall.

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