Sex differences of cognitive load effects on object-location binding memory

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Abstract In this study, we investigated where the sex differences of object-location binding memory performance were influenced by the cognitive load. We used the fractal objects version of the ‘What was where?’ task to measure object memory, location memory and objection-location binding memory. Cognitive load was controlled by task difficulty presented two sessions: one session randomly displayed three or four fractal objects (Session 34) and the other session four or five objects (Session 45). The results showed that females outperformed males on object-location binding memory. Interestingly, even when the four object trials were compared between Session 34 and Session 45, in which we believed that the level of difficulty was similar while cognitive load varied, the swap error of males was significantly increased in Session 45 compared to females. In conclusion, there may be sex differences in object-location binding memory and the males could be more sensitive about the cognitive load than females.

Keywords Object-location binding memory · Swap error measurement · Sex differences · Cognitive load

1 Introduction

Research on sex differences in spatial cognition has reported that there are distinct tests for male-favoring or female-favoring performance. Male-favoring has been observed on tests of mental rotation and spatial navigation [1–4]. In contrast, most tests of object-location memory have shown that females outperform males, particularly when presented objects can be easily verbalized [5]. These results depended on object type, such as common, geometric or masculine. In addition, females were shown to perform better than males in location memory (LM) under several conditions (when the objects have exchanged places, shifted position, or when new objects have been added to a previously seen array) across presentation formats including the paper-and-pencil test, computerized object arrays, virtual reality environments and internet-based test batteries [6–9]. However, a number of studies have reported no sex differences in object-location memory performance across presentation formats [10–15]. Indeed, some studies using computerized tests reported that males outperformed females when object-location memory performance was measured by distance, which can sensitively assess LM [13, 16]. In a recent study, object-location memory was measured using the absolute distance between the original location and participants’ responses using abstract objects to reduce the use of verbal strategies. The study reported that there were no sex differences in either object memory (OM) or LM of object-location memory [17]. The inconsistency of previous studies suggests that sex differences in object-location memory might be affected by two parameters: ease of verbalizing the object stimuli and sensitivity of the measurement tool used to detect object-location memory. To investigate the inconsistent results obtained regarding sex differences in object-

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location memory, we used the fractal objects version of the ‘What was where?’ task developed by Pertzov et al. to measure OM and LM performance in object-location memory under conditions that reduced the use of verbal strategies [18]. In particular, object-location memory performance was measured by ‘swap error’. The ‘swap error’ is defined as when participants relocate target objects around the locations of other presented objects rather than at random locations. This ‘swap error’ is not a simple failure of object identity or object location, but rather indicates failure to bind the object identity and object location in memory. Therefore, this measurement is more sensitive for object-location binding memory (OLBM) performance. The purpose of this study is to investigate sex differences in object-location memory by controlling cognitive load and using more sensitive measurements, including OM, LM and OLBM.

2 Methods

2.1 Subject

Forty undergraduate and graduate students were recruited from Hanyang University to control for education level. Participants were 20 males aged 22–32 years (mean = 26.4, SD = 2.76) and 20 females aged 19–34 years (mean = 24.4, SD = 3.89) and all of them has right handedness. There was no significant sex difference in age, $t(38) = 1.877, p = 0.07$. This study was approved by the institutional review board and all participants were given tutorials on the experiment and provided written informed consent.

2.2 Apparatus

We used the recently established Pertzov’s paradigm to measure OLBM with OM and LM during an object-location memory task [19]. In a brief description of the paradigm, fractal objects were displayed in random locations on a monitor for a few seconds, equal to the number of displayed fractal objects. After a delay in seconds equal to the number of objects, a forced-choice between one of the displayed fractal objects and a foil fractal object followed. Participants then dragged the selected object to the remembered location of the original target fractal object using the mouse (Fig. 1). When an object was correctly identified, the distance was computed for the visual angle between the center of the selected fractal object after it was dragged to its remembered location by the participant and the center of the fractal object in the initial memory array. Pixel values were converted to visual angle values with a 1920×1080 pixel matrix corresponding to approximately $67^\circ \times 44^\circ$ of the visual angle for a viewing distance of

42 cm. Localization memory is the distance computed using the target fractal object of the original array. Since fractal objects of the original arrays were never located within 9° of each other, the threshold eccentricity was 4.5° .

2.3 Procedure

The original paradigm assessed the participants’ ability to remember the identity of objects and their location using one or three fractal objects. In this study, we modified the number of fractal objects to control the cognitive load by the difficulty of the task. Participants undertook two sessions: one session randomly displayed three or four fractal objects (Session 34) and the other session four or five objects (Session 45). Each session involved 50 trials for each number of fractal objects, so therefore 100 trials were performed in total in a session. Each subject participated in two different sessions with a few days interval in a random order.

2.4 Measure and analysis

OM performance was measured by the rates of correct fractal selection in the two alternative forced choices. In addition, LM performance was defined as the number of trials in which the error distance was equal to or shorter than 4.5° for the visual angle between the center of the selected fractal object after it was dragged to its remembered location by the participant and the centers of any fractal objects in the initial memory array. Two types of performance were measured as OLBM. First, object-location binding performance was measured according to the number of trials in which participants located a target fractal object in its original location within 4.5° visual angle error distance. Second, swap error was estimated. Swap error occurs when a participant swaps the location of a target fractal object with that of another fractal object in the array, excluding the trials with incorrect identifications. Thus ‘swap errors’ counts the number of trials in which the

Fig. 1 Experimental protocol. In Session 34, three or four fractal objects were displayed and in Session 45, four or five objects were displayed. After a few seconds’ delay, participants selected the fractal object shown in the previous display. If that was the correct selection, participants dragged the selected object to its remembered location using the mouse

minimum distance is equal to or less than 4.5° for the visual angle, but with a target distance longer than 4.5° [19]. All analyses of the comparison were designed using 2×2 mixed repeated ANOVA (Analysis Of Variance). Factors included sessions (Session 34 vs Session 45) as a within-subjects factor and sex (male vs female) as a between-subjects factor. Statistical analyses were performed by IBM SPSS version 21.0 (Corp., Released 2012).

3 Results

In OM performance, the rate of identifying the correct fractal was significantly higher in Session 34 than Session 45, as shown in Fig. 2a ($F_{(1,38)} = 8.54$, $p = 0.006$, $\eta_p^2 = 0.183$). However, there were no sex differences or interactions between sex and difficulty ($F_{(1,38)} < 0.001$, $p = 0.99$, $\eta_p^2 < 0.001$ and $F_{(1,38)} = 2.15$, $p = 0.15$, $\eta_p^2 = 0.054$ respectively). For LM there were no significant differences in sex, difficulty, or interactions (respectively $F_{(1,38)} = 0.31$, $p = 0.58$, $\eta_p^2 = 0.008$, $F_{(1,38)} = 0.32$, $p = 0.57$, $\eta_p^2 = 0.008$ and $F_{(1,38)} = 0.40$, $p = 0.53$, $\eta_p^2 = 0.01$) (Fig. 2b).

In OLBM, correct object-location binding performance varied significantly with task difficulty ($F_{(1,38)} = 10.32$, $p = 0.003$, $\eta_p^2 = 0.213$), but not sex, similar to object memory (Fig. 3a). In contrast to correct OLBM, females had fewer swap errors than males in Session 45, although there were no sex differences in Session 34 (Fig. 3b). Therefore, in swap errors, the effect of task difficulty was significant ($F_{(1,38)} = 27.89$, $p < 0.001$, $\eta_p^2 = 0.423$) and the interaction between cognitive workload and sex was also significant ($F_{(1,38)} = 11.14$, $p = 0.002$, $\eta_p^2 = 0.227$).

In addition, we analyzed only four fractal display conditions in Session 34 and Session 45. Even though the difficulty level was the same in both sessions, males had more swap errors in Session 45 compared to females ($F_{(1,38)} = 28.26$, $p < 0.001$, $\eta_p^2 = 0.427$) and the interaction effect was also significant ($F_{(1,38)} = 11.55$, $p = 0.002$, $\eta_p^2 = 0.233$, Fig. 3c).

4 Discussion

In the present study, the use of swap errors enabled sensitive measurement of OLBM performance, and we demonstrated that females outperformed males in an object-location memory task. In particular, compared to females, males had more swap errors, even for the same task difficulty level (four fractal objects displayed), if the task condition required a greater mental load.

In an object-location memory paradigm, three different types of memory need to be considered and analyzed due to possibility of these separate processes: OM, LM, and OLBM [20, 21]. For the identification performance task

Fig. 2 Results of OM and LM performance. **a** The percentage of times subjects touched the correct object in the two alternative forced choices. **b** The percentage of times subjects dragged the selected fractal object to its original location

representing OM in our study, there were no sex differences, as shown in Fig. 2a. This finding is consistent with previous studies that have reported no sex differences in OM with uncommon or abstract objects minimizing female verbal superiority [17, 22, 23]. In addition, we estimated LM by counting the number of trials in which participants located the fractal to any location in the initial memory array. Interestingly, there were no significant differences in sex or difficulty. Previous studies have reported that males showed higher performance in LM [16]. This discrepancy might be due to the different paradigms used to measure LM. We instructed participants to drag the selected fractal object to its remembered location using the mouse. Subsequently, the number of trials in which the error distance between the remembered location and the center of any fractal object in the initial memory array was within the 4.5° visual angle criterion. Therefore, LM in this study might include some portion of OLBM.

Fig. 3 Results of OLB performance. **a** The number of times the original location of the target objects was accurately remembered. **b** The number of times target objects were localized in proximity to remembered locations of non-target items. **c** Swap errors for four fractals in Session 34 and Session 45

With regard to the correct object-location binding performance measured as OLB, there were no sex differences. In contrast to correct object-location binding, the swap error showed better female performance, as shown in Fig. 3b. In other words, there was a significant sex difference in swap error, not in correct object location. As described previously, sex differences in OLB has been a controversial issue. Some studies have reported female-favoring in OLB [6], whereas others have reported that males outperformed females when object-location memory performance was measured by distance, which can sensitively assess the spatial component of object-location memory [13, 16]. In addition, a number of studies have reported no sex differences in object-location memory performance across presentation formats [10–15]. This discrepancy seems to be due to the different object types and how they were measured. Generally, a strategy similar to the assessment of object-location binding performance used in this study has been utilized to estimate OLB, which scores how well subjects remember the location of the original object. However, this score could be affected by both OM and LM, as well as OLB, because subjects need to memorize the objects and their locations for OLB. Swap error was estimated in the present study as an alternative OLB index by counting how often participants confused an object's location for that of another object. With regard to the meaning of OLB, swap error could represent binding memory itself by excluding the effects of OM or LM. Pertzov et al. demonstrated that swap error could be a very sensitive parameter for measuring OLB, even in hippocampus-damaged patients. Our results also confirmed that swap error could be used as an OLB measurement.

In general, task difficulty influenced OLB performance. As the number of objects to be memorized increased, performance decreased. However, one of our most interesting findings is that the swap error of males increased at a higher rate in difficult sessions compared to females, as shown in Fig. 3b. When only the four-object trials from Session 34 and Session 45 were compared, in which the level of difficulty was presumed to be similar but with varying cognitive load, the swap error of males was significantly increased in Session 45 compared to females.

Although this study demonstrated that females outperformed males in OLB and that swap error is a very sensitive index of OLB, the small number of subjects in the present study could be considered to be a limitation. In addition, no neuropsychological tests for memory were performed, although students with a similar education level were recruited from the same university.

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