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A Novel Visuospatial Working Memory Task to Explore the Effect of Memory Load and Performance

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Abstract Visuospatial working memory is an essential cognitive ability that enables us to encode, maintain, manipulate and retrieve information in visual space to facilitate the action of ongoing activity. Despite having pivotal role across a range of daily activities, visuospatial working memory needs further exploration. Previous studies have used task paradigm, which do not simulate day-to-day activity. We designed a novel task involving simultaneous encoding, retention, active manipulation and retrieval, which we do routinely for executing daily activities like driving, cooking etc. In the current study, we aimed to investigate the effect of memory load and performance on visuospatial working memory using a novel task paradigm. We speculated that the increase in visuospatial memory load could help in elucidating the difference in the performance level among humans. Participants were grouped into two groups i.e. good and poor performers, based on the total number of errors committed in the task paradigm. Two-way ANOVA was applied to examine the effect of memory load and performance level on the number of errors committed and the search time taken by the participants. In the higher memory load, the errors committed and the search time taken by the participants significantly increased. We found that the discrimination between good from poor performers is more apparent from the errors committed in the higher memory load. More interestingly, we could not find any difference in the search time taken by the good performers from the poor performers. The outcome of the current study could be of help to improve our understanding on the neural basis of visuospatial working memory and possibly be applied to screen candidates for the job recruitment that demands visuospatial working memory.

Keywords Visuospatial Working Memory, Novel Task Design, Working Memory Load, Performance, Working Memory Capacity, Active Manipulation

1. Introduction

Memory is the process by which selective information from the environment is encoded, stored, manipulated and later retrieved when it is required. Working Memory (WM) is considered to be a cognitive component that temporarily maintains information that was either perceived but is no longer present in the environment, or that was internally generated, and it supplies a work space for transforming and manipulating elements of perception and thinking [1]. Therefore, WM is relevant for a successful interaction with the environment and it is therefore not surprising that WM is a central topic of research in the field of cognitive neuroscience. This interest is further increased by the fact that WM is seen as a limited resource that constrains cognitive performances [2-4]. The concept of working memory was proposed by Baddeley and Hitch (1974) due to the dissatisfaction with the idea of a single short-term storage and processing system, characterized most notably in the Atkinson and Shiffrin (1968) model [5, 6]. According to Baddeley's model, the Phonological Loop (PL) stores verbal information and it maintains this information by inner speech. In contrast, the Visuospatial Sketchpad (VSSP) stores visuospatial information and a kind of mental inspection was the presumed maintenance mechanism. The Central Executive (CE) controls these two slave systems. Baddeley suggested that processing, storage and maintenance of visual and verbal information are independent from the results of his behavioral experiments involving dual task with visual and verbal stimuli [7]. Capacity to remember visual information is not limited by the simultaneous verbal information since there is parallel processing of both simultaneously. Additionally, each system has its own limited capacity and therefore selective interference was postulated if two tasks tapping the same system were performed concurrently. As a consequence, one should avoid loading the same system to accomplish two tasks at the same time. Active manipulation of the incoming information is the fundamental characteristic of working memory. Evidences suggest that active manipulation poses more demand on the cognitive

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resources than mere maintenance of information [8]. Mohr and Linden (2005) suggested that passive and active processes in visuospatial working memory (VSWM) should be distinguished as well. Passive processes are recruited by the tasks that require recall of information in the same format as it was memorized, while active processes are recruited by tasks that require the information to be modified, transformed, integrated or otherwise manipulated [8]. Tasks, which were used in the previous studies, were N-Back task, Modified Sternberg memory paradigm, delayed match-to-sample task [9-12]. In these tasks, subjects have to respond either yes or no and hence subjects do not actively search for the execution of the VSWM task. These tasks required the subjects to memorize the sample items displayed during the encoding period, merely maintain for a few seconds in the delay period and respond by comparing the test item with the sample items in the retrieval period. Task design of the paradigms used in the previous studies limited the active manipulation of the information. Hence, with physiological point of view, we found that visuo-spatial working memory has to be investigated in a better method which simulates day to day activity involving encoding, storage, manipulation and retrieval simultaneously. In the current study, we used a novel VSWM task involving active manipulation of the encoded visuospatial information while simultaneously maintaining and retrieving the information for the execution of the task goal. We aimed to investigate the effect of memory load and the level of performance on VSWM in healthy human subjects.

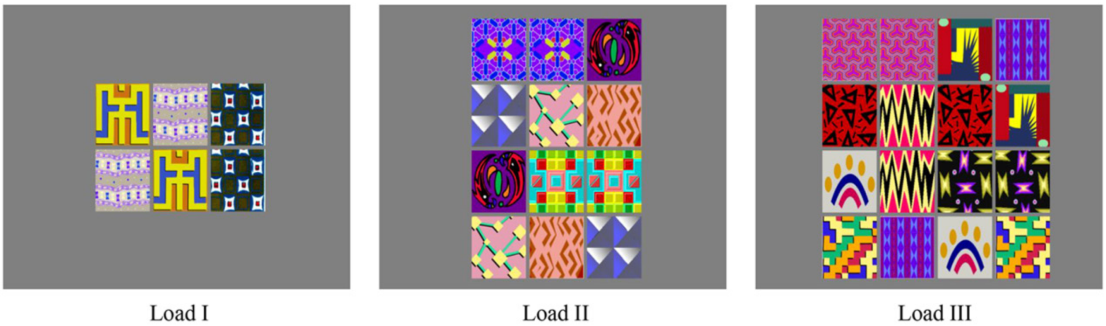

Figure 1. Each block of a memory load begins with an array of abstract pictures displayed for 10 s during which the pairs of identical abstract pictures in different spatial location in the array has to be encoded and maintained. 3, 6 & 8 pairs of abstract pictures were displayed in memory load I, II and III

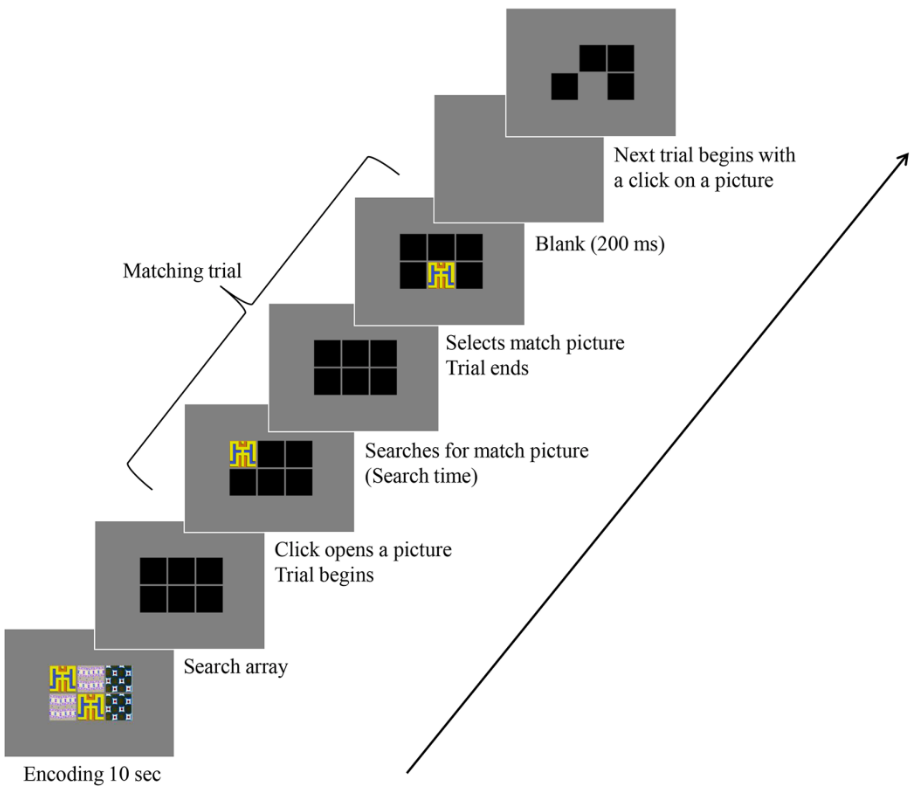

Figure 2. VSWM Task Design. Trial begins with a click opening a picture in the search array. Participant searches for the matching picture in the search array (Search time). Trial ends with the closure of the matching picture (1 s after selecting the matching picture)

2. Materials and Methods

2.1. Participants

Twenty four healthy male volunteers (mean age 27.63 ± 3.004; range 21-34; all right handed) participated in the experiment after giving written informed consent. Participants recruited were the post-graduate students and the resident doctors in the institute. The study was approved by the Institution Ethics Committee, All India Institute of Medical Sciences, New Delhi, India.

2.2. Task Design

This study has been designed with an objective to investigate the effect of memory load and performance level using a novel VSWM task involving simultaneous encoding, retention & retrieval in healthy human subjects. VSWM task consisted of three memory loads (3 pairs, 6 pairs and 8 pairs of identical abstract pictures) (Figure 1). Pictures used in the task were multi-coloured abstract designs obtained from an online database [13]. Abstract pictures were used rather than real life objects to minimize the contribution of verbal working memory for performing the VSWM task. In each load, participants had to encode the picture for 10 seconds after which pictures were hidden in the array. The pictures in the hidden array turn unhidden with the mouse click (Figure 1). Matching trial starts with a mouse click to turn open a picture in the search array for 1 second after which participant starts searching for the matching picture located elsewhere in the array (Search time) (Figure 2). Then, the participant clicks open a picture chosen as the matching picture which is displayed for 1 second. Successful matching trial makes the pair of abstract pictures to disappear from the array. After a matching trial, the display turns blank for 200 ms, after which the array appears with the hidden pictures yet to be matched. The correct match makes the pair of abstract pictures to disappear from the array. Search time involves simultaneous retrieval of the matching pair of pictures, retention of the spatial position of the remaining pictures in the array and recoding of the spatial position of the picture opened with the current click. All the pictures had to be matched to complete the load. In memory load I, 2 x 3 array of three pairs of abstract pictures (each unit consist of two identical abstract pictures in different spatial location in the array) were presented for 10 seconds during which the spatial location of the abstract pictures has to be encoded. Three pair of pictures has to be correctly matched to complete memory load I. Memory load II consist of 3 x 4 array of six pairs of abstract pictures and memory load III consist of 4 x 4 array of eight pairs of abstract pictures. Similar to memory load I, in memory load II and III abstract pictures has to encoded for 10 seconds and all pairs of abstract pictures has to be matched correctly to complete the load. Different sets of abstract pictures were used for each block of the memory load to avoid repetition of the abstract pictures used already in the task. Memory load I, memory load II and memory load III had three, two and one blocks of trials, respectively making at least 8 trials in each memory load. Matlab R2012b (The MathWorks, Inc., Natick, USA) software was used to design the paradigm and to record the events for further analysis. Array was displayed in the black background at the centre of the monitor screen. Participants were seated at a distance of 70 cm from the monitor screen. Each picture in the array subtended a visual angle of 4.2° and 4.5° in the horizontal and vertical axis, respectively.

2.3. Statistical Analysis

Statistical analysis was carried out using Statistical Package for Social Sciences version 20.0. Two-way ANOVA was applied to examine the effect of memory load and performance over the number of errors and the search time. Significant results were further investigated post-hoc applying a Bonferroni correction of $p<0.05$.

3. Results

3.1. Performance Group

Table 1. Descriptive Data of the Total Number of Errors by the Subjects

Mean	8.71
Median	8.50
Mode	6.00
SD	4.18
Range	17.00
25 Percentile	6.00
50 Percentile	8.50

Table 2. Number of Errors Committed by the Poor Performance Group (N=12) in Memory Loads

Subject No.	Age	Load I	Load II	Load III	Total Error
1	31	2	3	9	14
2	30	2	6	8	16
4	29	0	2	8	10
5	28	0	2	7	9
12	25	0	3	6	9
13	26	0	0	9	9
15	28	0	2	7	9
16	26	0	3	16	19
17	27	0	1	14	15
18	29	0	4	6	10
20	21	0	1	9	10
23	27	1	1	10	12

Descriptive data of the total number of errors in all the memory loads committed by the subjects is shown in the Table 1. Mean (SD) of total errors = 8.71 (4.18), Median = 8.5 and 50^{th} Percentile = 8.5. Hence, the total error of 8 was chosen as a cut-off value to distinguish the subjects as good performance group (≤ than 8 total errors; n=12) and poor performance group (> 9 total errors; n=12). Both the groups were age matched (there was no significant difference in age between groups). Number of errors committed by the subjects is given in the Table 2 and Table 3. Number of subjects who committed errors in load I were 4, load II were 19 and in load III all the subjects committed errors.

Table 3. Number of Errors Committed by the Good Performance Group (N=12) in Memory Loads

Subject No.	Age	Load I	Load II	Load III	Total Error
3	25	0	1	3	4
6	29	0	2	4	6
7	29	0	2	6	8
8	34	0	0	6	6
9	28	2	3	3	8
10	26	0	0	6	6
11	26	0	4	1	5
14	25	0	0	5	5
19	33	0	1	5	6
21	31	0	0	8	8
22	28	0	1	1	2
24	22	0	1	2	3

3.2. Memory Load and Performance Effect on Errors Committed

The effect of memory load, performance level and their interaction were very significant on the number of errors ($p = 0.008$). Post-hoc analysis showed that the number of errors committed in load III was significantly higher compared to load I and load III (Figure 3). In load III, there was significant increase in the number of errors committed by the poor performers compared with the good performers. There was significant load and performance interaction, because the number of errors committed in load III compared to load II was high in poor performers. In simpler terms, the poor performers committed more number of errors in load III compared to load II.

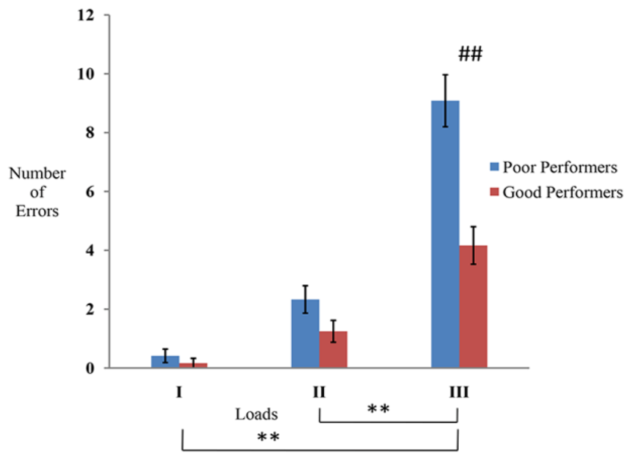

Figure 3. Effect of Memory Load and Performance on Number of Errors. ** - Memory Load Effect $p < 0.001$, ## - Performance Effect $p < 0.001$

3.3. Memory Load and Performance Effect on Search Time

Memory load affected the search time significantly ($p= 0.01$), while performance and load & performance interaction had no effect. Post-hoc analysis showed that the search time was significantly high in load II and load III compared to load I (Figure 4).

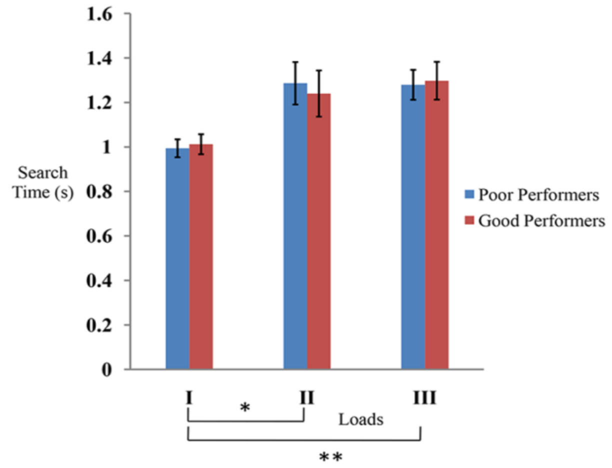

Figure 4. Effect of Memory Load and Performance on Search Time. *, ** - Memory Load Effect $p < 0.01$, $p <0.001$, Respectively

4. Discussion

In contrast to the reported studies in literature, in the current study a novel VSWM task involving simultaneous encoding, maintenance, manipulation and retrieval of the information was used. When faced with this task involving increasing memory load, four subjects committed errors in Load I that had three identical pairs of pictures in the array, whereas, all the subjects committed errors in Load III that had 8 identical pairs of pictures. This suggests that the number of items that a healthy human can process in visuospatial memory could be as less as three items (in few subjects) when they are required to simultaneous encode, retain the encoded information and retrieve the required information. This may be higher in other subjects, while may not exceed eight items in any subject. Previous literature also suggests similar number of items (3±1) as the memory capacity of humans [4]. Our results reveal that the number of errors and the search time increase with the increase in the VSWM memory load as demonstrated by the previous studies [2-4]. More interestingly, our results showed that the discrimination between the good versus poor performers becomes apparent only in the higher VSWM memory load. Further, the poor performers committed significantly more number of errors in load III compared to load II. In other words, work conditions demanding simultaneous encoding, retention and retrieval will bring out performance differences in the healthy human subjects. Another interesting observation is that, there was no difference in the search time between performance groups, though there was increase in the search time in higher VSWM loads for both the groups. This suggests that the faster processing of VSWM may not essentially mean better performance.

5. Conclusions

To summarize, despite playing an essential role for routine daily activities, neuropsychological correlates of visuospatial working memory and the inter-individual differences in the VSWM capacity remained unravelled. Evidence suggests that active manipulation poses more demand on cognitive resources than mere storage of visuospatial information [8]. Most previous studies have employed tasks that involved limited use of manipulation of visuospatial information [9-12]. We designed a novel VSWM task involving simultaneous encoding, retention, active manipulation and retrieval mimicking routine day-to-day activity. The current study aimed to elucidate the effect of memory load and performance level on visuospatial working memory performance utilizing a novel VSWM task which involves active manipulation of visuospatial information. We hypothesized that increase in the visuospatial memory load could help in elucidating inter-individual differences among humans. Our result reveals that when healthy human subjects are confronted with higher VSWM memory load, the error rate and the search time would increase significantly. Importantly, we found that the discrimination between good and poor performers becomes obvious from the error rate in the higher VSWM memory load. To our surprise, we could not find any significant difference in the search time between good performers and poor performers.

The outcome of the current study could possibly be applied for the candidates' recruitment for the jobs which demand visuospatial working memory like pilots, sailors, military soldiers etc. Further, the task used in this study could be of substantial importance to study the underlying neural basis of inter-individual differences in the visuospatial working memory capacity.

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