Proceedings of the 2nd International Conference on Modern Medicine and Global Health
DOI: 10.54254/2753-8818/8/20240385

The neuropsychological mechanism in loci memory using 7T fMRI

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Abstract. Memory has been a preoccupation of human civilization for centuries, and people have been searching for ways to increase its capacity and special memorisation methods tend to get more attention. Though efficient memory methods have always been a goal pursued by humans, the physiological nature still demands proper explanation. In this paper, a memory method called loci memorize is explored in the hope of obtaining a comparison of the level of activity in a particular region. This work utilized a 7T fMRI with a high resolution to unlock the neurological activity during quick memory of unordered numbers in eleven right-handed memory athletes. By designing a specific numerical memory task and initiating the task in two different groups of people, the coordinates of activated brain regions were located by analysing the degree of activity, with reference to the corresponding recall data. Results showed that brain activations associated with the loci memory were found in the middle cingulate, left precuneus, left supramarginal gyrus, left insula, left inferior frontal gyrus, left middle occipital, and right superior parietal lobule. These brain regions were more active in the group using loci memorise compared to that not using loci memorise under the same memory task. The preference for loci memory provides a possibility for the memory improvement. The work can be a reference of studying the memory mechanism in the neuropsychological science.

Keywords: Memory, fMRI, Loci Memory, Neurological Activity.

1. Introduction

Memory has always been a topic of concern in human civilization, and human beings have always explored the ability of memory in depth [1-3]. Memory can better help humans understand and adapt to society, and exceptional memory ability often attracts much attention. Now a memory method called loci memorization is gradually entering the public's field of vision. This method has been widely popularized among people with superior memory skills [4-6]. It aims to strengthen human memory and has attracted widespread attention in today's society.

Loci memorize is a special type of memory using encoding and spatial assistance [7]. Firstly, the things to be remembered need to be encoded, after which the encoded things are arranged in a specific story and placed at different spatial loci [8]. Dominic O'Brien, a distinguished octuple victor of the World Memory Championship, has demonstrated a distinct predilection for the utilization of the methodology.

Several studies exist on the brain activation and effects of loci memorization. Maguire et al. explored the activation of different brain loci produced by fMRI stimulation in response to different memory tasks

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(three-digit numbers, neutral avatars, regular snowflake patterns) [9]. For the first time, they suggested that the training group possessed more active brain region activation than the control group, and that there were even some brain regions that activated for the training group but no activation occurred for the control group. The speculation from activation in specific brain regions was also gradually transformed into an analysis of the activation network. The works of Dresler et al. also emphasized the importance of the medial temporal lobe in this process by analyses of network-based activation [10].

This article tries to answer the question that loci memorize will increase brain activity. The hypothesis is the degree of activation of different brain regions was obtained by comparing the group with loci memorize training (LCT) and the group with loci memorize normal (LMN). For this topic, 22 subjects were involved in the specific memory experiments with fMRI measurement. The experimental data for the training sets used in this paper were collected from the International Master of Memory certified by the World Memory Championships. The results of the article could be helpful for those engaged in the research on memory mechanism and those trying to improve their memory effects.

2. Methods

2.1. Participants

Eleven right-handed memory athletes of the World Memory Championships (four females and seven males, whose mean age was 23.4, with a standard deviation of 2.9 and a range of 16–26) were recruited. Eleven control participants (three females and eight males, whose mean age was 22.7, with a standard deviation of 2.6 and a range of 22–28) were matched for age, handedness. Every participant had regular or fixed-to-regular visual acuity, and none of them possessed any past of neurological or psychological disorder. The investigation was sanctioned by the Ethics Committee of the University.

2.2. Materials and procedure

A total of 240 one-digit numbers (0-9) were presented randomly using Psychology Software Tools E-Prime 3.0. During the fMRI scan, subjects were asked to remember the numbers and their order (sequence).

The experimental procedure was informed and the precautions to be taken was emphasised after participants have signed the letter of information. The subjects were then checked for discomfort or resistance after they entered the equipment and if not, the experiment was announced to begin. After the subject's initial entry into the device, the experiment allows the subject to rest for a period of time with their eyes closed to ensure that they will remain in a state of concentration in the task state. And at this moment a structural scan will be performed on the subject. At the end of the structural scan, the subject will be notified by voice that the resting state is about to begin. During the resting state, the screen will show the 'fixation' state (white plus sign on a black background as in figure 1(a)). Subjects were required to remain focused on the screen during this time, without closing their eyes and without being able to recall other things. After this stage, they will be asked to perform number memorisation. Memory content consists of the phase in which the numbers are presented and the phase in which the fixation occurs (black on white with a plus sign as in figure 1(b)), to compare the level of activity under different scenarios. Before the test starts, the subjects were asked not to make any recall or distract themselves from other things during the 'fixation' phase that occurs during the memory task. After the memory task had been concluded, the subjects were requested to recall the memory task. And use a standardised answer sheet (40-digit row) for the recall task (figure 2).

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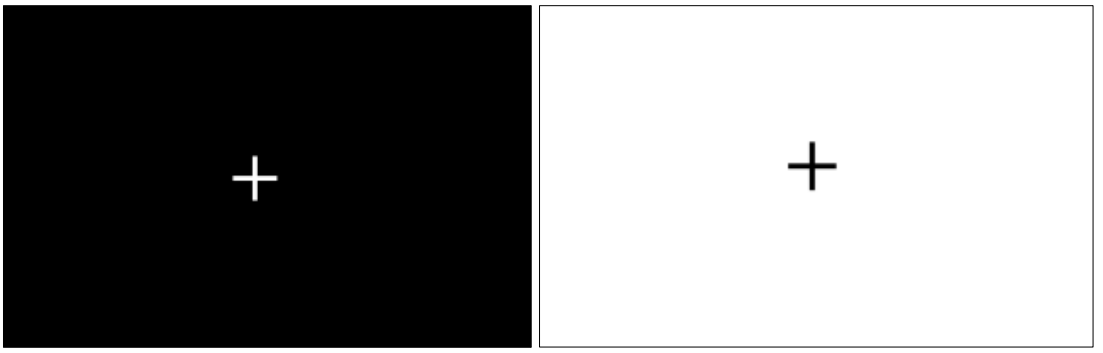

(a) (b)

Figure 1. The fixation state with graphs of (a) white plus sign on a black background or (b) black on white with a plus sign.

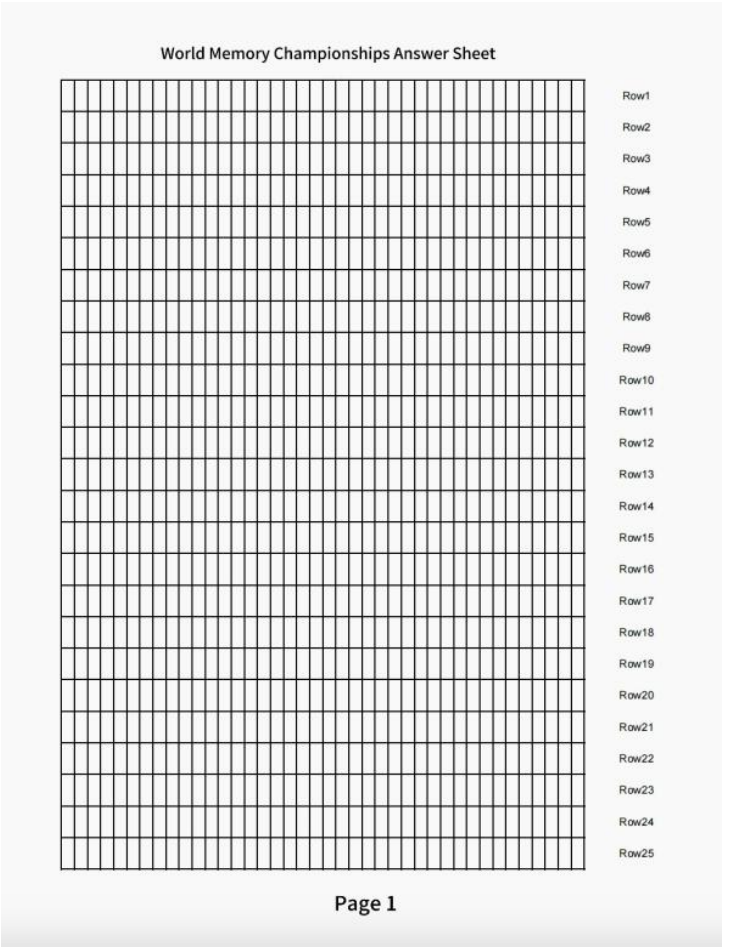

Figure 2. Standardised answer sheet (40-digit row) for the recall task.

2.3. MRI data acquisition

The imaging was done using a 7 T Siemens scanner (manufactured by Siemens Healthcare Sector, Erlangen, Germany) with a 32-channel head coil (from Nova Medical, Wilmington, MA, USA). A multiband gradient echo-planar imaging (EPI) sequence was utilized to acquire functional images where FOV was $192 \times 192\, mm^2$, matrix size was 192×192, voxel size was $1 \times 1\, mm^2$ with slice thickness of $1\, mm$ and slice gap of 0. Multi-band factor = 5, GRAPPA factor = 2. An acquisition of

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one hundred and twenty-five slices, with each slice tilted at 10 degrees from the AC-PC line, was made in order to cover the whole brain. Before the functional run, a T1-weighted sequence (MP2RAGE) was applied to acquire a high-resolution structural image, where TR = $5000\,ms$, TE = $2.38\,ms$, TI1 = $800\,ms$, TI2 = $2700\,ms$, Flip angle 1 = 7 degree, Flip angle 2 = 5 degree, 288 slices, slice thickness = $0.6\,mm$, FOV = $192 \times 192\,mm^2$, matrix size = 320×320, resolution = $0.6 \times 0.6\,mm^2$. To facilitate distortion correction, a field map was documented (85 slices, 10 degrees from the AC-PC line, $1.6\,mm/0\,mm$ slice thickness/gap, TR = $642\,ms$, TE1/TE2 = $4.08/5.1\,ms$, FOV = 208×208, an 130×130 matrix with a resolution of $1.6 \times 1.6\,mm^2$).

2.4. fMRI data analysis

Statistical parametric mapping (SPM12, Wellcome Department of Cognitive Neurology, London) was employed for data preprocessing and statistical analysis. All data were realigned to the spatial coordinates of the initial image of the first time series during data preprocessing. The functional data underwent the standard preprocessing procedures of normalization to the Montreal Neurological Institute template ($1 \times 1 \times 1\,mm^3$ voxel size) and spatial smoothing (by means of a 2-mm fullwidth half maximum isotropic Gaussian kernel). The general linear model from SPM12 was applied in the statistical analyses. Activations were identified by implementing a voxel level threshold of $p < 0.05$ with FDR corrected. A cluster size threshold (k) of 10 voxels was used to survive a correction.

3. Results

The answer and correctness of all subjects at the same time were calculated that:

LCT group: SD=35.9 Range=98.75 Average=38.8

LMN group: SD=1.9 Range=5 Average=1.4

Brain regions with different levels of activation were obtained through group analysis. Several more pronounced activations of brain regions were found and the coordinates of the activated brain regions were calculated (figure 3, table 1). It is simultaneously observed that different levels of significant activation were presented in Precuneus L (-8, -53, 66) (-11, -63, 66) (-16, -55, 61). The precuneus is circumscribed in the front by the marginal branch of the cingulate sulcus, in the rear by the parieto-occipital sulcus, and at the lower end by the subparietal sulcus.

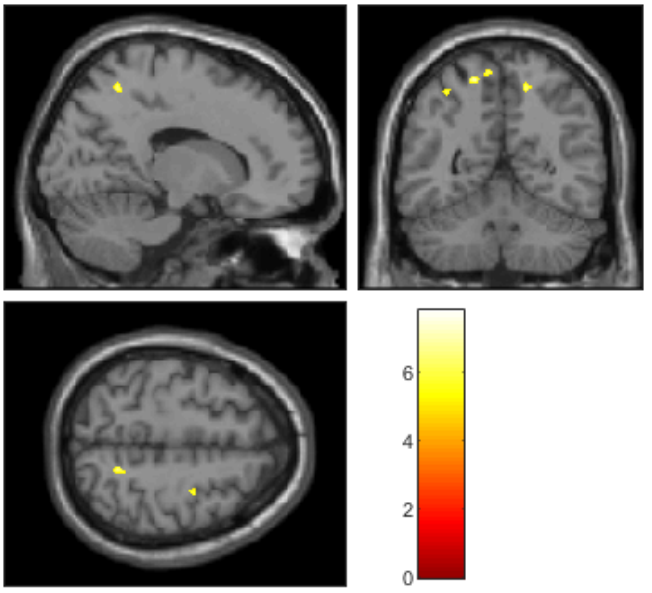

Figure 3. Brain activations of superior parietal lobule, precuneus, and supramarginal gyrus in contrast of LCT -LMN.

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Table 1. Regions showing significant activation in the contrast of LCT – LMN.

MNI			Region	T	Size
x	y	z			
-36	-1	14	insula	5.713	31
-50	36	14	Inferior Frontal Gyrus	5.876	11
-46	8	23	Inferior Frontal Gyrus	6.442	21
-26	-78	27	Occipital_Mid	6.249	10
-53	-22	27	Postcentral Gyrus	6.577	20
-60	-27	42	supramarginal gyrus	7.179	203
-1	7	37	Cingulate_Mid	7.802	27
-23	-66	45	Superior Parietal Lobule	6.303	14
-34	-54	53	Inferior Parietal Lobule	5.791	37
28	-9	52	Precentral, Frontal Lobe	6.050	83
16	-54	55	Superior Parietal Lobule	6.537	136
-16	-55	61	Precuneus_L	7.632	232
-25	2	61	Middle Frontal Gyrus	5.766	25
-8	-53	66	Precuneus_L	7.090	35
-11	-63	66	Precuneus_L	5.337	12

4. Discussion

This paper compared the activity levels of brain regions of trained versus untrained individuals by designing a digital memory paradigm and a resting state comparison.

Brain reinforcement has long been a topic of great interest, and we have conducted a more in-depth study of the reinforcement function of specific memory methods on memory. The correlations between activations are analysed with clearer and more accurate coordinates in the hope of finding ways to achieve specific activations also through non-training methods. To accomplish this objective, for the first time a 7 T Siemens scanner with higher parameters was used here. The aim was to achieve more accurate and clearer activation coordinates. Another consideration is the experimental paradigm that the number memorisation without training was performed for the participants.

To reveal the differences between the control group and the experimental group, group analyses were conducted (as shown in figure 3, table 1). Brain activations associated with the loci memory (LCT-LMN) were found in the middle cingulate, left precuneus, left supramarginal gyrus, left insula, left inferior frontal gyrus, left middle occipital, and right superior parietal lobule. Group analyses yielded that subjects found the most pronounced activation at the Cingulate Mid locus during the memory task.

The cingulate cortex is situated in the medial area of the cerebral cortex and is responsible for the formation and processing of emotions, learning, and memory. It is speculated that Cingulate Mid plays a role in learning and remembering this process. It is tentatively hypothesized that Precuneus_L functions as situational memory and visuospatial memory throughout the memorization process, since the LCT group will use loci memorize to activate spatial processing memory during the memory process.

5. Conclusion

Two groups of subjects were tested by designing a number memory task targeting loci memorize. Classification was performed by whether loci memorize was used or not, and group analysis was performed to determine the activation sites after acquiring the individual images. It was found that indeed in some specific brain regions, the LCT group showed a stronger activation contrast with the

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LMN group. Using the most advanced MRI equipment available and more informative parameter settings, this paper provides only a possible clear and reliable picture of the unique brain regions activated under digital memory.

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