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Sex differences in mental rotation: Cortical functional connectivity using direct transfer function

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ABSTRACT

Previous studies have reported that sex differences exist in mental rotation (MR) through different activated cortical regions, but it remains unclear what could be possible reasons of such differences in the different processing stages of MR. A few Event related potential (ERP) studies have noticed that sex differences occur in relatively early cognitive processing stages, but none of the study has viewed directional flow of information in the earlier stages as a function of complexity in men and women. This study investigated possible reasons for sex differences in visuospatial performance by flux of information underlying cortical functional connectivity. In the present study, earlier two stages were identified as a) perceptual encoding, identification, and discrimination of objects, kept under visuospatial attention allocation network (VSAN) and b) rotation ability involving spatial transformation strategy, assigned in mental rotation network (MRN). Participants underwent 3D mental rotation task with varying difficulty levels, simultaneously having electroencephalogram (EEG). It has been confirmed in behavioural outcome, as angular disparity increases, reaction and accuracy trades off. There were different activated electrodes in male and female participants for both networks. Advantage of spatial working memory was evident in men and reflected during performance. Also, VSAN showed that men utilised bottom-up attentional processes for more rotated views. MRN exhibited hemispheric lateralisation in the parietal cortex; men showed higher activation in right parietal cortex. This research work offers promising perspective to the study of cortical functional connectivity, in the terms of strength and direction, during sub-processes of MR.

1. Introduction

Several studies have confirmed sex differences in the visuospatial task performances, especially the mental rotation (MR) [1]. The engrossed causes of differences are biological [2], environmental [3], hemispheric lateralisation [4], and neurological factors [5]. In extension to environmental factors, sex differences are evident due to different adopted strategies i.e. male tends to prefer holistic strategy while female tends to use analytic strategy [6]. These kind of strategies differ in the efficiency of information processing, which results in male outscoring female in MR task. In addition, biological factors show higher activation of dorsal prefrontal cortices in woman, connecting visuospatial task with effortful “top-down” processing, while higher activation in basal ganglia and left precuneus in man, exhibiting effortless “bottom-up” processing [7]. Recent ERP study showed that sex differences in the performance followed time course in the 3D MR task [8]. This finding emphasized that the effect of sex can be identified in the sub-processes of MR task. In the MR task, people are asked to compare two figures and judge whether they are same (identical objects) or not (mirror objects) [9]. This task consists of several processing stages: (1) perception encoding and identification of stimuli, (2) mental rotation, (3) comparison, (4) response selection and (5) response execution. The stages are in sequential manner [10] or parallel manner is still under debate [11,12]. As mentioned in the earlier studies, assessment of sex differences in the sub-processes of complex MR task can be achieved through temporal mesurement like Event related potential (ERP) [13,8]. ERP allows decomposition of cognitive processes into a sequence of processing stages. ERP result suggests that sex difference occur at the very beginning of the MR task, before the rotation effect, in the visual cognition process. For example, Yu et al. [8] observed mental rotation effects at 900–1000 ms poststim-

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ulus at parietal electrodes and at 600–700 as well as 800–900 ms poststimulus at right frontal electrodes, respectively. However, sex differences were noticed at 400–700 ms poststimulus at right frontal electrodes, indicating disparity in relatively early cognitive processing stages.

On the contrary, another study pointed out that visual cognition process precede mental rotation process but also temporally overlaps it [13]. Authors used frontopolar N350 representing the visual cognition process which was observed in the superior parietal lobule (SPL), Ventral caudal intra parietal sulcus (vcIPS), and inferotemporal sulcus (ITS) regions, involved in the spatial representation, spatial transformations, and computing spatial relations respectively [13]. All of these findings suggest that sex differences appear either before rotation process or overlap with rotation process. None of these study has performed directed information flow technique between different electrode pair engaged in the sub-processes. The lacuna of applying an appropriate technique allows us to investigate directed flux of information in the functional connectivity to compare sex differences in the sub-processes. To determine causes of sex differences in the processes of MR as a function of the complexity, we have applied Direct transfer function (DTF). The purpose of the study, therefore, is to explore earlier sub-processes in 3D MR task by investigating flux of information in networks of visuospatial attention allocation (VSAN) and mental rotation (MRN). It should be noted that these networks are hypothetically considered for visibility of the interpretation and they have no neurobiological constructs or regions. Previous literature explained that sex differences occur at the very beginning of the MR when perceptual encoding take place and later on it get shifted to rotation ability, also. Therefore, both VSAN and MRN are assigned to each sub-process i.e. visual cognition and mental rotation ability respectively. As VSAN is used to classify top-down processing and bottom-up processing, the parietal cortex is considered as primary region of interest. The parietal cortex has been associated with the spatial information processing (sensory saliency detection) [14] and allocation of attention (bottom-up and top-down) [15]. Recent findings in the parietal cortex supported dual attentional processes (DAP) hypothesis [16]. This hypothesis states that top-down attentional processes take place in dorsal parietal cortex (DPC), involving superior parietal lobule (SPL), whereas bottom-up attentional processes occur in ventral parietal cortex (VPC), including inferior parietal lobule (IPL) and temporal-parietal junction (TPJ). DAP contributes to construct VSAN in which eight EEG channel locations are distributed in the parietal brain regions (SPL → P3 and P4, IPL → P7 and P8,TPJ → TP7 and TP8). Along with these locations in VSAN, we have included P5 and P6, also. Furthermore, EEG locations for MRN are identified using dipole fitting method (detailed in Methods section). This network consists of seven EEG channel locations, P1,P2,Pz,Fz,Cz,C4,and C1.

2. Materials and methods

2.1. Participants

Thirty healthy subjects (15 males and 15 females) participated in this study. All the subjects were informed about the task procedure and a signed written informed consent form was obtained prior to the recording of EEG signals. The subjects did not report any neurological illness and were free of medications. All of them were accustomed for using the computer console. An appropriate information regarding the task was provided to the subjects.

2.2. Stimuli

Stimuli were white geometrical figures on black background, motivated from Shepard and Metzler's stimuli [17]. Figures were presented in 6 different orientations (angle of rotation between a pair), starting at 0° and rotated clockwise to 50°, 80°, 100°, 150°, and 180°. Figures in orientation of 0°, 50°, and 80° were considered as easy stimuli because it would take lesser mental effort to mentally rotate the stimuli as compared to tough stimuli which included orientation of 100°, 150°, and 180° . This classification was executed on the basis of previous studies which indicated that major sex differences were obtained for an angular disparity of 100° (Fig. 1). All stimuli were presented on a 17" Lenovo laptop, at a distance of 70 cm, subtending angle of 6°. Experimental program ran on Unity 5.0 software.

2.3. Procedure

Judgment of parity task was used to capture mental rotation process. Eighty trials of the three-dimensional geometrical shapes were presented as a pair in front of the participants. The experiment began with twenty practice trials having feedback for the each response. Every premise was portrayed for 10s. During the 10secs, the subject had to see and decide whether the two shapes shown on the screen were the same or not and accordingly press the button as correct or incorrect respectively. After each trial, 3secs inter-stimulus interval consisting of a blank slide was shown. Forty easy stimuli and forty tough stimuli were presented in the random order and performance was recorded automatically in the text file. Performance were assessed through variables, accuracy (ACC) and response time (RT).

2.4. EEG recording & analysis

EEG recording was conducted by means of Ag/AgCl electrodes located in an electrode cap at 64 positions (Advanced Neuro Technology, Enschede, Netherlands). These locations followed the

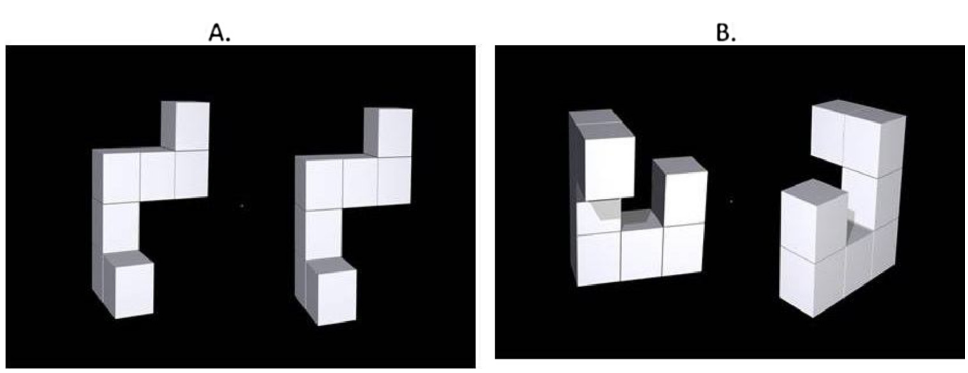

Fig. 1. Stimuli used for Mental rotation task [37]. A. represents stimulus for easy trial while B. represents stimulus for tough trial.