CORTICAL ACTIVITY DURING MENTAL ROTATION PROCESS: A REVIEW

Nisha Jangra[1], Ravish Garg[2], Greeshma Sharma[3], Sushil Chandra[4]
[1,2]Department of Biomedical Engineering, GJUS&T, Hisar, Haryana (INDIA)
[3,4]Biomedical Engineering department, INMAS, DRDO, Timarpur, Delhi (INDIA)

Abstract: The complexity of the human brain and the associated processes has been a great source of fascination for the neuroscientists. Mental Rotation (MR) is a classical psychological course of action characterized by the mental repositioning of an object. Men have been found to be outperforming females in MR task in many studies; performance of females can be improved with training. The anterior intra parietal area is concerned with the size and/ or orientation of the object while the lateral part records the intended saccadic movements during perception. The dorsal occipitotemporal cortex (DOT) calculates the spatial characteristics while the superior-parietal cortex is linked with visuo-spatial transformations. Precuneus has vital roles in highly integrated tasks and communicates with the visual information processing areas. Moreover, dorsolateral premotor area (dPM) shows the highest activity during the MR proper step of the entire MR process. The cortical activation patterns have been inconsistent with regards to the involvement of motor cortex.
Keywords: Mental Rotation, Cognition, Gender differences, Activated cortical areas

I. BRAIN AND MENTAL ROTATION TASK

The intelligence and the associated mental processes in the brain of an individual have attracted the attention of almost everyone on the face of this earth once in a while. The human brain is known to be the most complex living structure in this universe that has a lot of networks that continuously interact with each other [1], [2]. This has been a great source of fascination to the people involved in the area of cognitive science for decades. The term ‘cognitive neuroscience’ is generally used in a wider sense and is basically concerned with a very vast field that encompasses many mental processes and the mental phenomenon associated with it[3]. Over the years, researchers over the world have been working to find the brain areas related with a specific task when a person is busy in that particular task [4]. Mental Rotation (MR) is a hypothesized classical psychological process that is concerned with the visuospatial ability of an individual and has long been a subject of interest among the neuroscientists in spatial ability domain [5], [6], [7], [8].Shepard and Metzler were the scientists who investigated and introduced the process of MR in cognitive science in the year 1971 which was an innovative rotation technique for the effects of visual imagery[9], [10]. The creation and manipulation of the visual images in the brain is important for a wide range of cognitive functions. In the famous experiment performed by Shepard and Metzler, the subjects were presented with pictures of two three-dimensional objects/ figures at different orientations and the figures portrayed were either same but rotated in a plane or they were incongruent [10]. The subject had to see and decide as to the shown figures were same or not. The concept has been reported to be showing some similarities with the visual information processing tasks concerned with the visual and spatial ability [11]. MR tasks, are generally used for the study of spatial intelligence in cognitive neuroscience [4].MR typically engages two fundamental cognitive processes; creation and the manipulation of images formed within one’s brain. Of these, the latter process can be used to improve the cognitive capacities and abilities[6].MR has also been said to be composed of a set of processes. It has been verified by numerous research papers based on EEG, fMRI and SPECT etc. and the results are indicative of the fact that the MR process is altogether accomplished by a multitude of processes that occur synchronously while many sub-processes are being carried out at the different cortical regions [12]. In the contextual demand arising out of a very broad range of the researches being done with MR, and the desirability to use uniform stimulus material, a library of 16 cube MR figures was designed and developed [13]. Though the experimental studies can be done with the MR of classical three-dimensional objects or abstract figures or letters, the MR of three-dimensional objects is best because it produces stronger cortical hemodynamic responsesthan the MR of other stimulus objects used in all of the activated areas. This might be attributed to the geometrical aspects of the three-dimensional objects which tends to gather more attention from the subjects as they need to focus on the stimuli to discern the geometrical aspects of the figures[14]. Based on the study described above, numerous experiments have been performed to understand the brain responses, processes and examining the regional activation of the brain during mental rotation task performance employing electrophysiological methods, positron emission tomography, and functional magnetic resonance imaging[11], [15]. Here, this article presents a bird of the eye view of the results that have been produced in the several studies involving MR task over the years. Having knowledge of this, we would be able to train the persons who are not good at the task using neuro-feedback techniques. The further scope of the paper has been discussed in the later section.

II. GENDER DIFFERENCES IN MR

In the recent years, scientists have regained interest in studying the sex differences related with the cognitive ability variables. In the cognitive neuroscience, some of the strongest and largest differences with respect to gender differences have been found in the visuospatial abilities. In this context, the classical MR task introduced by Shepard and Metzler has consistently produced the largest gender differences in the visuospatial domain[7]. The sex differences for the tasks that require the mental repositioning of three-dimensional objects, have been found to be in favor of the men[14], [16], [17], [18].The gender differences observed in the MR task have been attributed to the various environmental and biological influencing factors. While the environmental factors are based on the Social Quotient (SQ), spatial activities, the biological factors are due to genetics, evolution, and hormones[14], [19].Other impending factors contributing to the well pronounced gender differences that are part of the environmental influences include learning strategies or sex stereotypes over the years[17]. Sex hormones influence also influence spatial perception by affecting the development of the brain systems involved in spatial functions during early or later development period[19],[20], [21]. In a study to find the variations between children and college students in MR task, it has been found that although there were differences between men and women in terms of hemispheric activations, no such differences were found between boys and girls[16]. In an attempt to study if there were any sex related differences for different age groups and to question whether differences if any increased with age, it was found that for both the sexes, MR score increased with age. It was also found that the increase was more rapid and steep in males as compared to females. In short, there occurs a slight improvement in the MR task performance as the age increases [18]. While most of the studies have been found to be in favor of men, contradictory and case specific results could also be found[22]. It has also been portrayed that the advantage of being a male in an MR task totally disappears when the stimuli are presented in true three-dimensional models. Also, the performance in the mental repositioning task can be improved with practice of several computer gamessuch as Tetris, three-dimensional Tetris or action video games. Novelty of a task also affects the MR performance and hence in general the performance of woman can be improved with training upto the level of men[7].The results of sex differences has also been related to the dimensionality where it has been shown that women were at parity with the men in case of three-dimensional task but no gender difference has been found in case of two-dimensional task [23].Not only computer games have the ability to improve the performance of women in MR task, the performance of females is also affected by the positive instructions, beliefs and expectations about their class of gender[24]. Differences have also been arising due to the difference in strategies used by both men and women. The men accomplish the task by an approach where they use coordinates, representations, in a continuum of space whereby the two spatial transformations can be transformed by changing the intermediary points. On the contrary, women tend to fulfill the task at hand by serially rotating as parts rather than the gestalt [25]. The differences had been represented in terms of activation patterns.In case of female, gender-specific activations of both the hemispheres have also been found, this is in line with what had been shown by Voyer in 1996. Voyer showed that women in general exhibit more bilaterally with regards to psychological functions[26], [27].MR task demands the usage of complex problem solving strategies and different cortical activation patterns has been reported. Women tend to show additional activation patterns to those that were found in common with the activation patterns of men [28].In a study in which 134,317 men and 120,783 women participated, clear gender differences in MR task were observed where men outperformed women [19].

III. INFERENCES FROM DIFFERENT BRAIN ACTIVATION STUDIES

Several research papers based on the imaging of the brain have reported the activation of different cortical regions of the brain during the MR task performance. According to Zacks et al, there was consistent activation of the superior parietal, frontal, and inferotemporal cortex. All the activated brain areas were bilaterally active. However, they reported the consistently more activity in the right parietal cortex and the left hemisphere of the frontal cortex. They also reported the activation of the superior parietal cortex and implied an important role of this region in the visuo-spatial image transformations. Lateral inferior prefrontal cortex and the superior parietal cortex were also portrayed to play important roles in motor planning[8]. Irina M. Harris et al used PET study to find the active brain area during the MR of alphanumeric characters and they found significant activation of the right posterior parietal lobule, centered on the intraparietal sulcus (IPS). The authors attributed that the parietal activations can more confidently be related to the MR task performance. They also reviewed the evidence for the mental rotation that recruits IPS and the superior parietal lobule for visuo-spatial transformations. Also, the anterior intraparietal area responds selectively to the size and/or orientation of an object [11]. Andrea E. Cavanna et al found a central role of the posterior-medial portion of the parietal lobe called the precuneus. This area of the parietal lobe played a crucial role in several highly integrated tasks as visuo-spatial imagery, episodic memory retrieval and self-processing operations etc. To be specific, the anterior subdivision of the precuneus is involved in self-centered MR strategies, and the posterior sub-division sub-serves successful episodic memory retrieval. The area has also been reported to be connected with inferior and superior parietal lobules (SPLs), and the IPS which are known to be involved in visuo-spatial information processing [29]. Moreover, different regions of the intraparietal area are involved in different processes of a MR task. The lateral intraparietal area lying inside the IPS forestalls the recording of intended saccadic movements of the retina and causes the firing of nerve cells that present a memory trace of the visual stimulus. The anterior part of the intraparietal area responds to the size and/ or orientation of the object [8], [11], [30].

The dorsal region of the posterior cortex called the Dorsal Foci 1 (DF1) and the Dorsal Foci 2 (DF2) are normally and routinely active during the perception of the object, even if it is passive viewing. ventro-caudal Intraparietal Sulcus (vcIPS) and DF1 analyze structure of the object and if needed can perform the transformation to achieve a task goal. Also, the dorsal occipitotemporal cortex (DOT) has a role of computing the two- and three-dimensional spatial characteristics of the object to perform the specified task [30], [31], [32], [33]. E. Charles Leek et al suggest that pre-supplementary motor area (pre-SMA) provide support to non-motor sequence operations and has an involvement in visuo-spatial processing. The data provided by them showed that pre-SMA has a role which is extended to processes that go beyond the planning. Their findings also suggested a functional connection between the motor system and the visuo-spatial processing [34].ClaussLamm et al explicitly separated the processing steps required by mental rotation tasks and found that the activation of the dorsolateral premotor area (dPM) is strongest during the MR proper [35]. In a Positron Emission Tomography (PET) where two paradigms were used; a) subjects had to mentally rotate an alphanumeric stimuli and had to determine if it was shown in normal or mirror-image position, and b) the subjects had to mentally rotate the one of the two figures in the two figures shown in the task and had to decide if the two were identical or mirror images. It was deciphered that in the first paradigm, left precentralgyrus was significantly activated in the alphanumeric condition and left gyruslingualis showed up significant activation in the paired figures condition [36]. The brain activation patterns are also affected by the different kinds of stimulus pairs of stimuli used for the experimental study. Moreover, the neuroimaging studies done over the years have not shown to be consistent in their results about the involvement of motor processes in mental rotation. On one side, where activation of Brodmann Area 6 (BA 6) was activated, contrary to this, other studyshowed bilateral activation of the premotor cortex and the supplementary motor area[37], [38].

IV. CONCLUSION

The parietal lobe of the brain has been elicited to be confidently related with the mental rotation task performance. Additionally, its different regions are involved in the different processing steps of the task procedure. The anterior and the lateral intraparietal area, interprets size and/ or orientation of an object and records the intended saccadic movements of the eye, respectively. DOT computes spatial characteristics of the object (2-dimensional or 3-dimensional). Superior-parietal cortex is linked with the visuo-spatial transformations. The precuneus plays an important role in several highly integrated tasks (such as imagery, episodic memory retrieval and self-processing operations) and is linked to the other areas of the brain involved in visuo-spatial information processing. In addition, dPM has shown to have the strongest activation during MR proper. It was also found that, the activation of brain areas is also affected by the kind of figures used in the MR task. There is inconsistency with regard to the involvement of motor areas.

V. FUTURE SCOPE

After a crime has occurred, crime investigators reach the place of incidence and start the process of investigation according to the training that has been provided to them as per the personnel management of their department. Now, in these crime scenes some objects lie scattered (rotated in the technical terms). Providing neural feedback training to these investigators and sleuths can help us in expediting the process of investigation as there is the improvement of an individual with these neural feedback processes. Also, we can improve the performances of individual in the aptitude tests involving MR stimuli. However, the time of response for observing, mentally rotate and identify the object might be reduced slightly but it will surely help improve the performance of the police staff and the investigators of the crime. All this is possible only if we are well acquainted with the brain areas involved in the MR task procedure. Furthermore, the training can also be used to improve the performance of the individuals appearing in the aptitude tests involving MR of objects.

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