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INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY

International Journal of Psychophysiology 50 (2003) 235–246
www.elsevier.com/locate/ijpsycho

Two- and three-dimensional mental rotation tasks lead to different parietal laterality for men and women

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Received 13 January 2003; received in revised form 15 July 2003; accepted 22 July 2003

Abstract

Thirty-two college students (16 male, 16 female) had EEG recorded during computerized two- and three-dimensional mental rotation tasks. The simple two-dimensional mental rotation task was associated with more left parietal than right parietal activation in men and more right parietal than left parietal activation in women. The complex three-dimensional mental rotation task was associated with greater right parietal than left parietal activation in both men and women. Men performed better than women on the three-dimensional task and there were no differences between men and women on the two-dimensional task. It was concluded that men and women may be using different neurological strategies on two- and three-dimensional mental rotation tasks.

Keywords: Mental rotation; Electroencephalogram (EEG) activation; Sex differences

1. Introduction

Although the cerebral hemispheres were once considered task specific, current observations view the hemispheres are more process-oriented. Thus, the resources of the right hemisphere appear to be specialized for information processing in a way conducive for analyzing spatially-oriented data and the resources of the left hemisphere appear specialized for processing verbally-oriented data (Banich and Heller, 1998). Research illustrations can be found for both clinic and non-clinic samples. For example, patients with damage to the right posterior area of the brain are reported to make more errors than individuals with damage to the left posterior area of the brain on a spatial task that requires mental rotation to an inverted position (Ratliff, 1979). Likewise, patients with damage to the right parietal area make more errors and take longer to respond on a mental rotation task than either patients with damage to the left parietal lobe or control participants (Ditunno and Mann, 1990).

A non-invasive way of examining brain processing in non-clinical populations has been with the use of the electroencephalogram (EEG). Typically, adult EEG recordings made in a state of cognitive functioning or attentional load exhibit reduced alpha (8–13 Hz) power values at various

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0167-8760/03/$ - see front matter
doi:10.1016/S0167-8760(03)00195-8

scalp locations. This is sometimes referred to as *alpha suppression* or *EEG activation*, and is considered to exemplify activation of particular brain areas (Hugdahl, 1995). For instance, there are reports of EEG activation in the hemisphere most engaged in the processing of either verbal or spatial information (e.g. Davidson et al., 1990; Furst, 1976; Willis et al., 1979).

Researchers of brain electrical activity in healthy research participants have found greater activation of the right parietal area than the left parietal area during spatial tasks. When research participants completed psychometrically matched verbal and spatial cognitive tasks, the spatial task produced more right parietal 8–13 Hz EEG suppression than left parietal suppression, indicating more right parietal activation during the task. Conversely, the verbal task produced more left central 8–13 Hz EEG suppression than right central suppression, indicating left central activation (Davidson et al., 1990). In a study using the dual measures of EEG evoked potentials (EPs) and regional cerebral blood flow (rCBF), mental rotation task performance was associated with greater activation in the right parietal than the left parietal regions (Papanicolaou et al., 1987).

It has also been found that alpha suppression in the parietal and occipital regions increases with angle of displacement in a mental rotation task (Michel et al., 1994). Research participants were asked if an abstract probe figure was the same as a memory figure that was presented earlier at a different orientation. As the angle of the figure rotated further from the original position, there was an increase in alpha suppression, as well as an increase in reaction time. In a study using functional magnetic resonance imaging (fMRI), brain functioning was compared while participants were determining if two figures were the same (Cohen et al., 1996). The figures were in either a rotation or a non-rotation condition, and the areas most activated during the rotation condition (as compared to the non-rotation condition) were the superior parietal and frontal eye field areas. Likewise, a different fMRI study found that both the left and right precentral gyrus, as well as the right superior parietal lobule, were the areas most activated during a mental rotation task (Tagaris et al., 1998). Thus, it appears that the right parietal area is a part of various brain systems intimately involved in the processing of spatial information, with other brain areas contributing as well.

There is in the literature, however, a suggestion that rotation of simple two-dimensional stimuli can lead to greater activation of the left parietal area rather than the right parietal area. In a Positron Emission Tomography (PET) study, participants were required to discriminate whether stimuli were 'normal' or 'mirror image' at various angles. The task required mental rotation and the stimuli were simple alphanumeric stimuli, resulting in a two-dimensional rotation task. The task elicited greater activation of the left parietal and right frontal areas than of the homologous locations (Alivisatos and Petrides, 1997). Likewise, a left hemisphere advantage for the rotation of both alphanumeric characters and figures from the Primary Mental Abilities test has been reported (Fischer and Pellegrino, 1988). Furthermore, greater left parietal and left posterior temporal EEG activation, relative to right parental and posterior temporal, has been noted in adult males, but not adult females, using a two-dimensional mental rotation task (Roberts and Bell, 2000). The rotations in each of these three studies are considered 'simple' because they consisted of flat, two-dimensional figures (alphanumeric characters or line drawings) rotated on one axis. In contrast, most of the classic mental rotation literature has used more complex rotations consisting of complicated three-dimensional block drawings rotated on more than one axis. Therefore, it could be the case that simple rotations lead to activation of brain systems including the left parietal area, while more complex rotations lead to activation of brain systems including the right parietal area. In the literature, however, there are no studies that have tested this hypothesis.

The purpose of this study was to test the hypothesis that simple, two-dimensional, rotation tasks are associated with greater left parietal EEG activation than right parietal activation, whereas more complex, three dimensional, rotation tasks are associated with more right parietal EEG activation than left parietal activation. In light of the data that suggests sex differences in laterality between men and women on mental rotation and other cognitive tasks (Kimura, 1999), it was specifically hypothesized that on the two-dimensional rotation task that men would exhibit greater left parietal activation than right and women would exhibit more right parietal activation than left. On the three-dimensional task it was hypothesized that both men and women would exhibit more right parietal activation than left parietal activation. It was assumed that men would perform better than women. The results of recent meta-analyses have documented that, in adult populations, there is an overall male advantage on spatial tasks, with the most robust sex differences appearing on tasks of three-dimensional mental rotation (Linn and Petersen, 1985; Voyer et al., 1995).

2. Method

2.1. Participants

Thirty-two right-handed college students (16 men, mean age = 19.86; 16 women, mean age = 19.82) who were free of medications and neurological diagnosis were recruited through the Introductory Psychology extra credit pool to participate in this study. Participants were compensated for their participation with extra credit in their Introductory Psychology class.[1]

2.2. EEG recording

A stretch cap (Electro-Cap, Inc.) with electrodes in the 10/20 placement system (Jasper, 1958) was used for EEG collection. Recordings were made from Fp1, Fp2 (frontal pole), F3, F4 (medial frontal), F7, F8 (lateral frontal), C3, C4 (central), T3, T4 (anterior temporal), T5, T6 (posterior temporal), P3, P4 (parietal), and O1, O2 (occipital). Recordings were made with the electrodes referenced to Cz and grounded anterior to Fz electrode on the Electro-Cap. After the cap was properly in place, recommended procedures regarding EEG data collection were followed (Pivik et al., 1993). First, Omni–Prep abrasive gel was inserted into each electrode to allow gentle abrasion of the scalp with the blunt end of a cotton-swab. Next, Electro-Gel conductive gel provided by the cap manufacturer was inserted into the 16 electrodes. Electrode impedances were less than 5 kΩ and less than 500 Ω separated homologous electrode pairs. EOG was digitized along with the EEG and used for later artifact editing. To collect the EOG data, Lead–Lok solid gel electrodes were applied to the supra orbit and outer canthus of the right eye after the skin had been wiped with an alcohol pad.

The electrical activity from each lead was amplified using SA Instrumentation Bio-Amps and bandpassed from 0.3 to 100 Hz. Activity for each lead was displayed on the monitor of the data acquisition computer. Data were digitized on-line at a sampling rate of 512 Hz using a Modular Instruments A/D board and SnapShot acquisition software. A high sampling rate was used to prevent aliasing and raw data were stored for later analysis.

Prior to the recording of each research participant, a 10 Hz sine wave was input through the amplifiers. The amplifiers were set so that output of that signal represented 50 uV peak to peak, with a gain of 20 000. This calibration signal was digitized for 30 s and stored. Spectral analysis of the calibration signal and computation of power at the 9–11 Hz frequency band was later accomplished. The power figures were used to calibrate the power derived from the subsequent spectral analysis of the EEG.

2.3. EEG analysis

The EEG data were examined and analyzed using software developed by the James Long Company (Canoga Lake, NY). First, the EEG data were re-referenced via software to an average reference configuration. This linear transformation was accomplished by means of an algebraic equation that, in effect, weighted all the electrode sites

[1] These data are part of a larger study examining the development of sex differences on spatial and verbal tasks (Roberts and Bell, 2002). The larger study involved 8-year-olds and college students on a battery of spatial and verbal tasks, examined sex by age interactions throughout the EEG recorded from the entire scalp during task performance, and included computerized and non-computerized tasks. The 8-year-olds did not complete the three-dimensional mental rotation task reported here, but otherwise completed the same tasks as the adults.

equally and eliminated the need for a non-cephalic reference. Active to reference electrode distances vary across the scalp, and without re-referencing, power values at each active site may reflect inter-electrode distance as much as they reflect electrical potential (Lehmann, 1987; Lehmann and Skrandies, 1984). The average reference configuration requires that a sufficient number of electrodes be sampled and that these electrodes be evenly distributed across the scalp. There is no agreement in the psychophysiology literature concerning the appropriate number of electrodes (Davidson et al., 2000; Hagemann et al., 2001).

The average reference data were artifact scored using EOG as a guide; thus, eye movements and blinks, along with gross motor and muscle movements, were removed through artifact scoring. Because these were adult data, artifact due to gross motor movements was very rare and mainly eye movements/blinks were detected. The artifact-scored epochs were eliminated from all subsequent analyses. Artifact-free EEG data were analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap. Power was computed for the 11–13 Hz frequency band and then the power was transformed using the natural log (ln) to normalize the distributions (Davidson et al., 2000).

Recent studies have indicated that the standard 8–13 Hz alpha EEG band actually may be comprised of two (or more) distinct higher and lower frequency bands that vary with respect to scalp distribution (Gevins et al., 1997; Klimesch, 1996). Particularly, studies have found that the lower alpha band (approx. 8–10 Hz) is usually found over prefrontal and parietal scalp locations and is sensitive to working memory load (Gevins and Smith, 2000). The higher alpha band (approx. 11–13 Hz) usually is found over parietal and occipital scalp locations and appears to be sensitive to visuospatial components of a task, as well as to task difficulty (Gevins et al., 1997). In light of this research, the high alpha band was of interest in this study. Because spatial tasks were employed in this study and because the tasks varied along dimension (two- vs. three-dimensions), it was expected that EEG activation during both tasks would be found in the higher alpha band. Previously we reported sex differences in 11–13 Hz hemispheric activation at parietal scalp sites during a two-dimensional mental rotation task (Roberts and Bell, 2002, 2000).

The EEG variable of interest was the laterality score. The laterality score for each participant was computed by subtracting left parietal EEG ln power values at 11–13 Hz from the right parietal EEG ln power values at 11–13 Hz (Davidson et al., 2000). Typically, EEG in the alpha frequency range is attenuated by attention–demanding tasks. Thus, a positive laterality score indicated left parietal activation (attenuated power values in the left hemisphere relative to the right hemisphere) and a negative laterality score indicated right parietal activation (attenuated power values in the right hemisphere relative to the left hemisphere).

2.4. Baseline EEG

Baseline EEG consisted of 1 min with eyes open, during which participants were instructed to look at a blank computer screen and think about a 'walk in the woods'. Participants were instructed to sit quietly without motor movements. After baseline EEG was recorded, the computer-based mental rotation tasks began.

2.5. Mental rotation tasks

Two-dimensional '*Gingerbread Man*' *Mental Rotation Task.* Participants were seated in front of a computer and shown the Overman Mental Rotation Task (Epting et al., 1996; Epting and Overman, 1998). This mental rotation task consisted of a 'Gingerbread Man' sample figure presented at the top of the computer screen, with two choices, one of which matched the original sample figure, presented at the bottom of the screen (see Fig. 1). Sample figures and choices, are computer-generated in such a manner that each had the same amount of area within its borders. The sample figure had four possible positions. While either the left or right arm was extended straight out, the opposite arm was either in an up or down position. During each trial of task performance, the participant was asked to match the sample figure at the top to one of two choices at the bottom. The

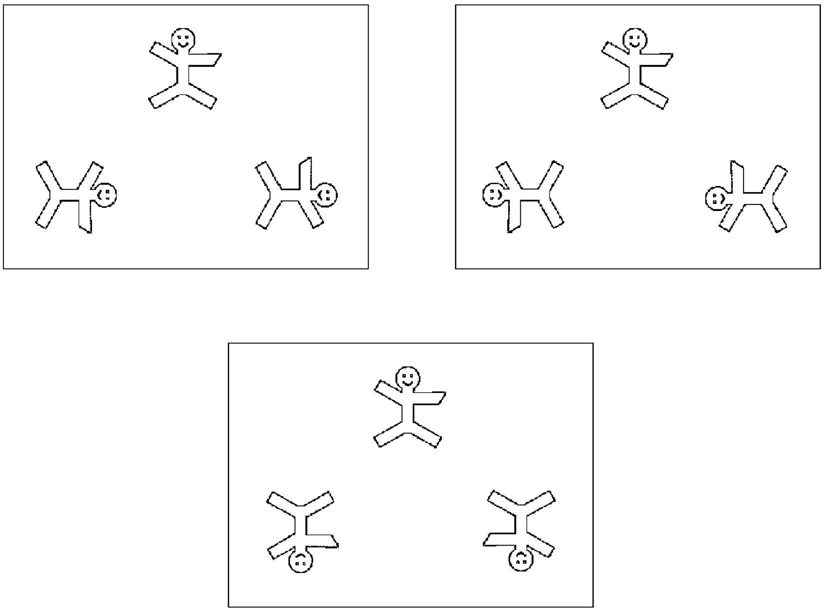

Fig. 1. Sample trials of the two-dimensional Gingerbread Man mental rotation task.

sample figure was always in an upright position, while the subsequent choices at the bottom were rotated 0, 90, 180 or 270°. Thus, for this task, choices were rotated along one axis.

Three-dimensional *Block Design Mental Rotation Task.* Participants were seated in front of a computer and shown the Block Design Task (adapted from Vandenberg and Kuse, 1978). This mental rotation task was similar to the one described above except that it consisted of a Block Design sample presented at the top of the computer screen, with two choices presented at the bottom of the screen, one of which could be turned in three-dimensions (i.e. along 2 axes) to match the original sample (see Fig. 2). During each trial of task performance, the participant was asked to match the sample figure at the top to one of two choices at the bottom.

For both mental rotation tasks, the entire keyboard was covered except for two keys, one on the right side of the keyboard and one on the left side of the keyboard, which the participants used to select the choice that correctly matched the sample figure. Additionally, the space bar was used to let the participants self-pace the time between trials. In order to minimize motor movements, hands were rested in such a manner that only finger movements were required. All trials were randomized in such a manner that correct responses were equally divided between the right and left choices, and the tasks were randomized such that participants were equally likely to perform either of the tasks first.

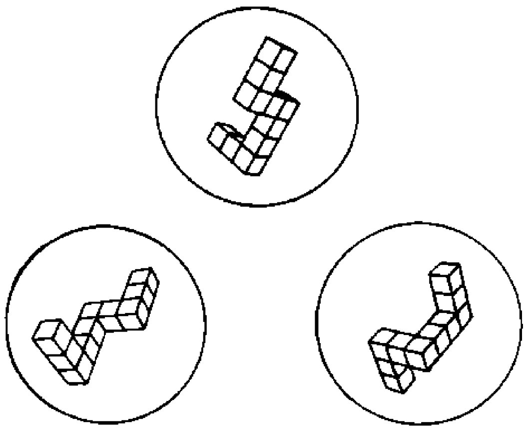

Fig. 2. Sample trial of the three-dimensional Block Design mental rotation task.

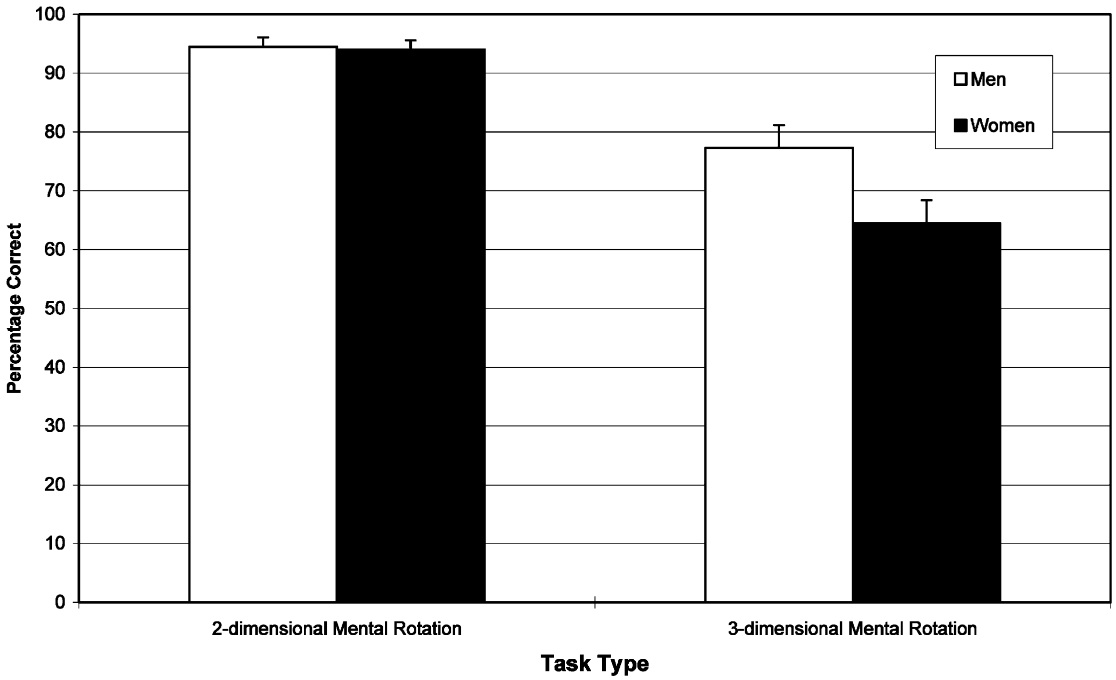

Fig. 3. Mental rotation task performance: task type by sex interaction.

Before beginning the experimental trials, participants were given one untimed practice trial to become familiar with the task procedure. On the three-dimensional Block Design task, one block of 16 trials was performed. On the two-dimensional Gingerbread Man task, participants were given two blocks of 16 trials. Thirty-two total trials on the Gingerbread Man task were given for a specific reason. Pilot data indicated that participants had much faster reaction times on the two-dimensional task, so more trials were necessary to obtain enough EEG data for meaningful analysis.

Performance was measured by percentage of correct trials. Participants' responses were recorded automatically by the computer and saved for later analysis. The computer program was set up in such a manner that the participant could respond any time after the choices were displayed on the screen. After making a selection, the computer screen displayed feedback to the participant to inform if the response was correct or incorrect. The participant then started the next trial by pressing the space bar.

3. Results

3.1. Task performance

To test the hypothesis that men would perform better than women on the mental rotation tasks, a repeated measures ANOVA was performed. The dependent variable was percentage of correct trials and the within-subjects independent variable was task type (three-dimensional task, two-dimensional task), with the between-subjects independent variable being sex. Analyses revealed a main effect of task type and a main effect of sex. These two main effects were superceded by a task type by sex interaction, $F(1,30)=5.62$, $P=0.03$. Post hoc analyses indicated that this interaction was driven by men having a higher percentage correct than women on the three-dimensional Block Design task, $t(30)=2.34$, $P=0.03$, whereas there was no difference between men and women on the two-dimensional Gingerbread Man task, $t(30)=0.226$, $P=0.82$ (see Fig. 3).

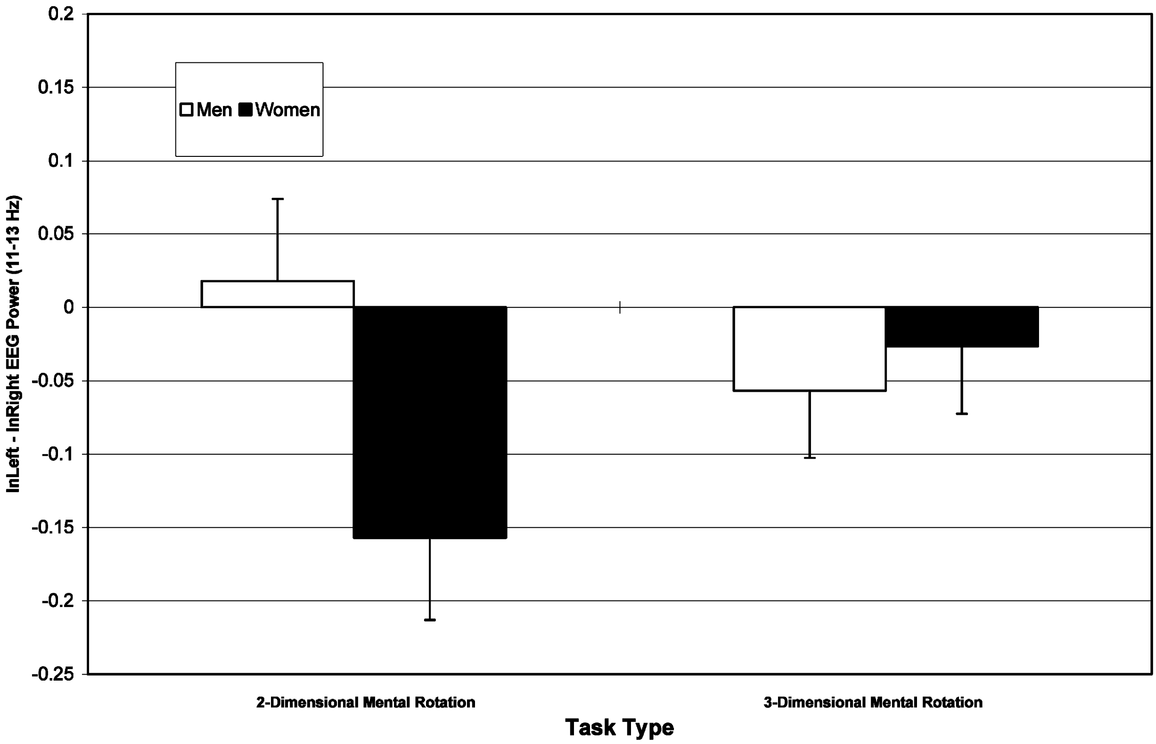

Fig. 4. EEG parietal laterality scores during mental rotation tasks: Task type by sex interaction. Laterality computed as lnRight–lnLeft. Zero signifies parietal symmetry during task; positive scores denote left parietal activation; negative scores denote right parietal activation.

3.2. Task-related EEG

For the EEG data, it was hypothesized that men would exhibit left parietal activation and women would exhibit right parietal activation two-dimensional rotation task, whereas both men and women would exhibit right parietal activation on the three-dimensional rotation task. In order to assure that any EEG effects found during task performance were specific to task performance itself, and not due to the influence of any sex difference in the baseline EEG measures, ANCOVA was used to control for baseline EEG power values. The within-subjects independent variable was task type (two-dimensional, three-dimensional), the between-subjects independent variable was sex, the dependent variable was the task-related EEG 11–13 Hz laterality score at the parietal scalp locations, and the covariate was baseline EEG 11–13 Hz laterality score at the parietal scalp locations.

ANCOVA analyses revealed a task type by sex interaction, $F(1,30)=6.05$, $P=0.02$. Post hoc analyses indicated that this interaction was driven by women exhibiting negative parietal EEG laterality scores (indicating greater right hemisphere activation) on the two-dimensional task and men exhibiting a positive mean laterality score (more indicative of greater left hemisphere activation), $t(30)=2.57$, $P\leq 0.02$. There were no differences in parietal EEG laterality between men and women on the three-dimensional task, $t(30)=0.37$, $P=0.71$ (see Fig. 4). There were no main effects for task type, $F(1,30)=0.64$, $P=0.43$, or sex, $F(1,30)=1.28$, $P=0.27$.

In order to examine variability in parietal EEG laterality scores among the men and women, laterality scores were plotted individually for each

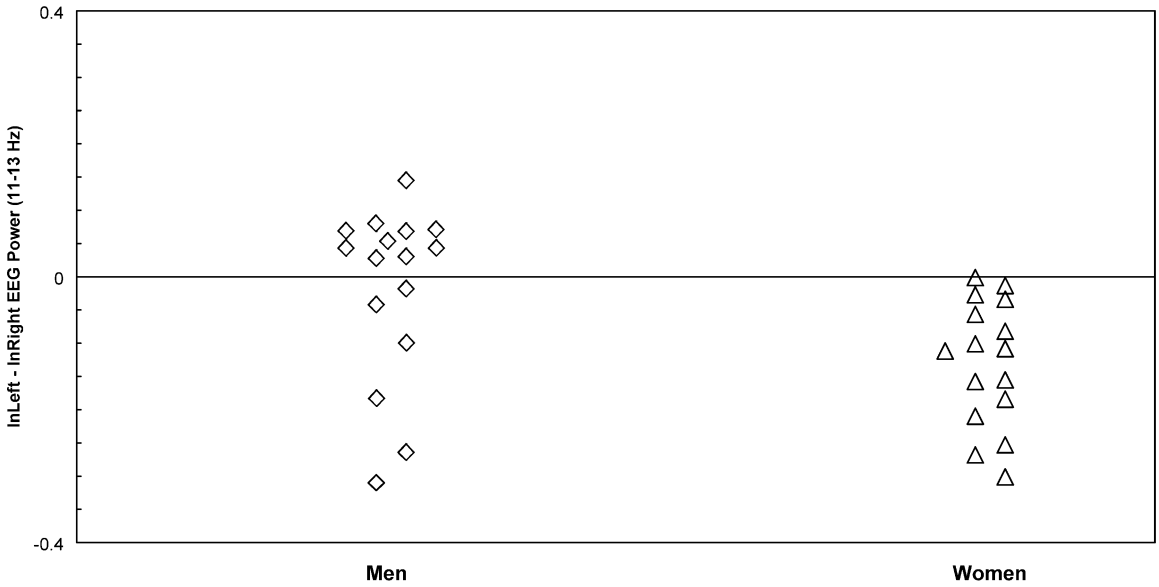

Fig. 5. Parietal laterality scores on the two-dimensional mental rotation task. Laterality computed as lnRight–lnLeft. Zero signifies parietal symmetry during task; positive scores denote left parietal activation; negative scores denote right parietal activation.

participant on the two-dimensional (see Fig. 5) and three-dimensional (see Fig. 6) tasks. Participants were categorized as exhibiting either right or left parietal activation during each task and chi-square analyses were performed. For these analyses, the variables were sex and hemisphere of activation (left, right; see Table 1). On the two-dimensional Gingerbread Man task the chi square analysis was significant, $\chi^2(1, N=32)=14.55$, $P<0.001$, with 62.5% of the men exhibiting left hemisphere activation (i.e. positive laterality scores) and 100% of the women exhibiting right parietal activation (i.e. negative laterality scores). The chi square test on the three-dimensional Block Design task also was significant, $\chi^2(1, N=32)=4.8$, $P=0.05$, with 81% of the men exhibiting right parietal activation and the women equally likely to exhibit left or right parietal activation.

4. Discussion

The purpose of this study was to test the hypothesis that simple two-dimensional rotation tasks are associated with more left parietal activation than right parietal activation in men and greater right parietal activation than left parietal activation in women, whereas more complex three-dimensional rotation tasks are associated with more right parietal activation than left parietal activation in both men and women. Although spatial tasks, and particularly mental rotation tasks, have traditionally been regarded as tasks involving right hemisphere processing (e.g. Berfield et al., 1986; Michel et al., 1994; Papanicolaou et al., 1987), the current study adds to the literature which indicates that simple, or two-dimensional, rotation tasks can lead to greater left hemisphere relative to right hemisphere activation (Alivisatos and Petrides, 1997), particularly in adult males (Roberts and Bell, 2002, 2000). Because the procedures of the two-dimensional and three-dimensional tasks were identical (other than the total number of trials on each task), there were no procedural differences in the current study that lead to left activation on the two-dimensional tasks.

The task performance results are typical of sex differences research. In this study, men performed better than women on the three-dimensional task and there was no difference between men and women on the two-dimensional task. Meta-analyses have indicated that the male advantage on mental rotation tasks is most robust on three-dimensional tasks (Linn and Petersen, 1985; Voyer et al., 1995).

The task performance and EEG results taken together may offer the most intriguing contributions of this study. On the two-dimensional mental rotation task, there was no difference in task performance between men and women, yet there were differences in parietal laterality. All of the 16 women in the study exhibited EEG patterns associated with greater right parietal activation relative to left parietal activation, while 10 of the 16 men exhibited the opposite pattern of greater left parietal activation. In this case, it appears that men and women may have been taking different brain processing routes to the same task performance results. On the three-dimensional mental rotation task, men performed better than women, and there were also differences in parietal laterality. Thirteen of the 16 men had EEG patterns associated with

Table 1
Parietal hemisphere of activation on the two-dimensional and three-dimensional mental rotation tasks

	Two-dimensional Gingerbread man mental rotation task[a]	
	Left activation	Right activation
Men	10	6
Women	0	16
	Three-dimensional block design mental rotation task[b]	
	Left activation	Right activation
Men	3	13
Women	9	7

Note: Left activation is associated with a positive laterality score, whereas right activation is associated with a negative laterality score.

[a] $\chi^2(1, N=32)=14.55$, $P<0.001$.

[b] $\chi^2(1, N=32)=4.8$, $P=0.05$.

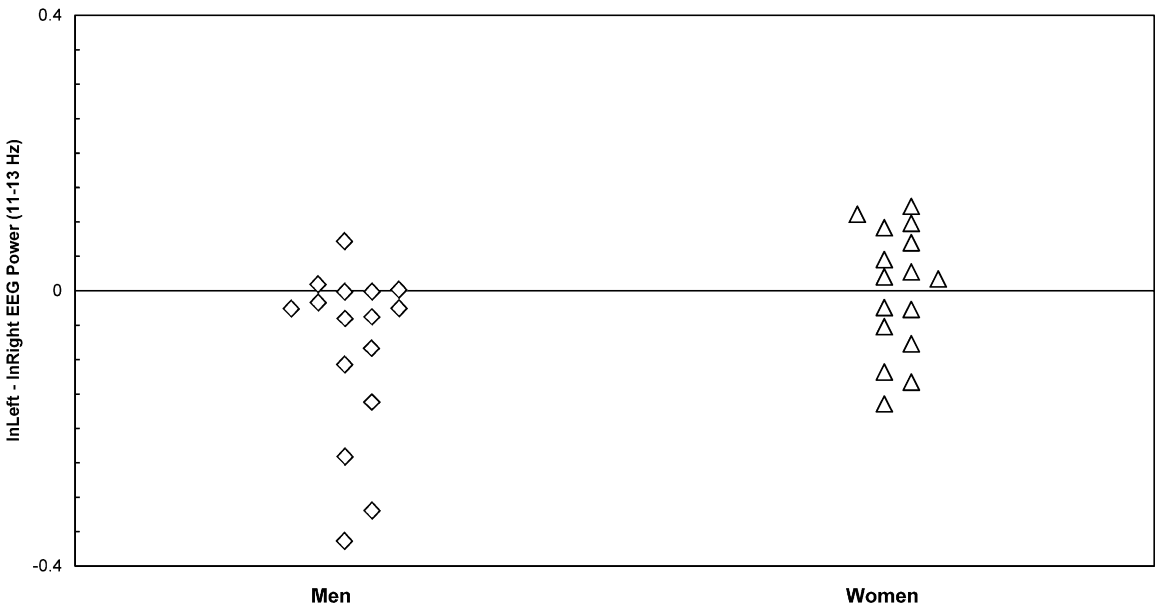

Fig. 6. Parietal laterality scores on the three-dimensional mental rotation task. Laterality computed as lnRight−lnLeft. Zero signifies parietal symmetry during task; positive scores denote left parietal activation; negative scores denote right parietal activation. Of the three men who appear to have laterality scores of zero, when examined to two decimal places, one had a positive score (left hemisphere activation) and two had negative scores (right hemisphere activation). It could be argued that these three participants displayed symmetry rather than laterality during task performance. For the purposes of these analyses, however, they were forced into a laterality category.

greater right parietal activation relative to left parietal. Seven of the 16 women had EEG patterns associated with more right parietal activation relative to left parietal. It should be noted that this was not predicted. We had hypothesized that both men and women would exhibit greater relative right parietal activation on the three-dimensional task.

Possible reasons for this sex by task type interaction are intriguing. First, on the three-dimensional mental rotation task, it could be that men are more likely to take a 'rotation' approach while women are less likely to take that approach. The rotation approach would more likely to lead to activation of the right parietal area (Michel et al., 1994) and better performance on the task. This may explain why the women had lower performance scores than men on the three-dimensional task. Second, it could be that rotations that are 'easy' to perform do not require the spatial information processing resources associated with the right hemisphere. If the two-dimensional rotation task were easier for men than for women, then men might not need to use their right hemisphere resources. The problem with this explanation is that there were no performance differences between men and women on the two-dimensional task.

Third, there is a body of literature to suggest that the information processing resources of the right hemisphere are more involved during task acquisition, whereas the information processing resources of the left hemisphere are more involved in solving familiar tasks (Bever and Chiarello, 1974; Goldberg and Costa, 1981). In a behavioral study examining hemispheric laterality and a two-dimensional mental rotation, Voyer (1995) concluded that the shift in laterality from right to left occurred sometime after 128 trials. To explain the current results in terms of Voyer's conclusions, men would need to have greater experience with two-dimensional mental rotations prior to completing the experiment, and would, therefore, be more prone to use their left hemisphere resources to process the information on the two-dimensional task. This may indeed be the case because research has indicated that men typically have more experience than women playing two-dimensional computer games (e.g. Barnett et al., 1997; Dominick, 1984; Phillips et al., 1995). Conversely, if the women lacked spatial experience rotating two-dimensional objects, then they may be more apt to use the processing resources of the right hemisphere during the two-dimensional task. This proposal would fail to account for men being more prone to use their right hemisphere on the three-dimensional task, unless of course they have little experience mentally rotating three-dimensional objects. In either scenario, it appears that men and women may be using different brain resources to process the data on these tasks.

One caveat about this study is the assumption that two-dimensional tasks are simple while three-dimensional tasks are complex. It could be that task difficulty, and not the dimension of the rotation, is the key difference to sex differences in task performance and EEG laterality. Manipulating the difficulty of both two- and three-dimensional rotation tasks could directly test this hypothesis. For example, using a relatively 'difficult' two-dimensional rotation task (e.g. Collins and Kimura, 1997) and a relatively 'easy' three-dimensional rotation task may show equivalent male/female performance on the three-dimensional task and a sex difference in performance on the two-dimensional task.

A second caveat of this study concerns the use of the EEG to assess parietal activation. Although the EEG has excellent temporal resolution, it has relatively poor spatial resolution. That is, the EEG accurately detects neurological changes associated with psychological state; however, these neurological changes may be the product of multiple cerebral sources (Davidson et al., 2000). Therefore, the EEG we recorded at left and right parietal scalp locations may have generators other than parietal ones. From a brain systems point of view this appears feasible; multiple brain areas are involved in information processing. Other research reports utilizing brain imaging techniques with excellent spatial resolution increase our confidence in the likelihood that the scalp EEG we recorded from the parietal areas are likely generated at this location, however. For example, work combining EEG evoked potentials and regional cerebral blood flow has demonstrated that performance on a mental rotation task was associated with greater right parietal than left parietal activation (Papanicolaou et al., 1987). Other work has directly compared EEG to regional cerebral blood flow at the same points in time and reported high correlations (Ingvar et al., 1976). Similarly, work using functional magnetic resonance imaging techniques has demonstrated that parietal and frontal eye field locations were more activated during the rotation conditions of a mental rotation task as compared to non-rotation conditions (Cohen et al., 1996). Obviously, combining techniques having excellent temporal resolution with those having excellent spatial resolution is ideal.

In conclusion, the results of this study suggest that men and women take different neurological approaches to mental rotation tasks. When examining individual data points, men exhibited patterns of greater left parietal activation than right parietal activation during a simple, two-dimensional mental rotation task and patterns of more right parietal activation than left parietal activation during a complex, three-dimensional mental rotation task. Women exhibited patterns of greater right parietal activation than left parietal activation during both tasks, but were more likely to do so during the two-dimensional task. Finding an explanation for these apparent sex differences in brain electrophysiology may yield insight into the possible effects of sex hormones and/or visuospatial experience on mental rotation performance.

Acknowledgments

We thank Ian Reed for his help designing the computer tasks and assisting in data collection. Additionally, we thank numerous other undergraduates for their assistance in data collection. Special thanks go to William Overman for use of his mental rotation task.

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