Brain and Cognition 69 (2009) 451–459

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Sex differences in parietal lobe morphology: Relationship to mental rotation performance

Tim Koscik [a,*], Dan O'Leary [a,b], David J. Moser [a,b], Nancy C. Andreasen [a,b], Peg Nopoulos [a,b]

[a] University of Iowa Neuroscience Graduate Program Drive, Department of Neurology, 200 Hawkins Drive, Iowa City, IA 52242, USA
[b] Department of Psychiatry, University of Iowa College of Medicine, Iowa City, IA, USA

ARTICLE INFO

Article history:
Accepted 23 September 2008
Available online 5 November 2008

Keywords:
Sex differences
Mental rotation
Parietal lobe
Spatial ability

ABSTRACT

Structural magnetic resonance imaging (MRI) studies of the human brain have reported evidence for sexual dimorphism. In addition to sex differences in overall cerebral volume, differences in the proportion of gray matter (GM) to white matter (WM) volume have been observed, particularly in the parietal lobe. To our knowledge there have been no studies examining the relationship between the sex differences in parietal lobe structure and function. The parietal lobe is thought to be involved in spatial ability, and particularly involved in mental rotation. The purpose of this study is to examine whether sex differences in parietal lobe structure are present, and if present to relate these differences to performance on the mental rotations test (MRT). We found that women had proportionately greater gray matter volume in the parietal lobe compared to men, and this morphologic difference was *disadvantageous* for women in terms of performance on the MRT. In contrast, we found that men compared to women had proportionately greater parietal lobe surface area, and this morphologic difference was associated with a performance *advantage* for men on mental rotation. These findings support the possibility that the sexual dimorphism in the structure of the parietal lobe is a neurobiological substrate for the sex difference in performance on the mental rotations test.

1. Introduction

Significant sex differences in the morphology of the human brain have been reported in multiple studies. Males have larger brains even after eliminating differences in body size (Marshall, 1892; Nopoulos, Flaum, O'Leary, & Andreasen, 2000; Raz et al., 2004; Sowell et al., 2006). In addition to the difference in size, there is evidence for sex differences in tissue proportions, with studies showing that women have proportionally greater gray matter (GM) volume than white matter (WM) volume compared to men (Goldstein et al., 2001; Gur et al., 1999; Luders et al., 2005). As a corollary to these studies evaluating volumes of tissue, imaging methods that map cortical thickness show increased cortical depth in women (Im et al., 2006; Luders et al., 2006; Sowell et al., 2006). A convergence of studies suggests that the proportional increase in gray matter in women is regionally specific to the parietal and posterior temporal lobes (Im et al., 2006; Luders et al., 2006; Nopoulos, Flaum, O'Leary, & Andreasen, 2000; Schlaepfer et al., 1995; Sowell et al., 2006).

The parietal lobes are thought to play an important role in spatial processing in general, and mental rotation specifically (Culham & Kanwisher, 2001; Jagaroo, 2004; Save & Poucet, 2000). Mental rotation is the act of imagining an object turning in space (Corballis, 1997), be it two-dimensional images such as alphanumeric objects rotating around a central axis or three-dimensional objects being manipulated in terms of pitch, yaw, and roll. A variety of functional imaging studies using PET (e.g., Alivisatos & Petrides, 1997), EEG (e.g., Roberts & Bell, 2000), and fMRI (e.g., Seurnick, Vingerhoets, de Lange, & Achten, 2004) have shown parietal lobe activation during mental rotation tasks. For example, as task demands are increased in a mental rotation task, activity in the superior parietal lobule increases (Tagaris et al., 1996). Lesion studies point to parietal involvement in spatial ability (see Corballis, 1997, for a review). Specifically, parietal lobe lesions result in deficits in mental rotation, which is in line with a broader role of the parietal lobe for spatial processing and neglect syndromes. It has been suggested that the right hemisphere may be dominant for mental rotation (e.g., Ditunno & Mann, 1990), however, left parietal involvement may increase with mental rotation difficulty (e.g., Mehta, Newcombe, & Damasio, 1987).

In addition to possible hemispheric differences in mental rotation, gender differences on spatial tasks have been reported. In these reports, men excel relative to women, particularly on tasks involving mental rotation (Collins & Kimura, 1997; Delgado & Prieto, 1996). Meta-analyses have demonstrated consistent sex differences in mental rotation performance (Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995). Moreover, a growing body of fMRI

* Corresponding author.
E-mail address: timothy-koscik@uiowa.edu (T. Koscik).

0278-2626/$ - see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandc.2008.09.004

studies has demonstrated sex differences in activation patterns between men and women on mental rotation tasks. For example, Jordan and colleagues (2002) observed bilateral activations in the parietal lobes, including superior and inferior parietal lobules and the intraparietal sulcus, inferior temporal gyrus, and premotor areas in women whereas they observed right parieto-occipital sulcus, left intraparietal sulcus, and left superior parietal lobule activation in men. Similarly, males have been observed to show predominantly parietal activation where females show additional inferior frontal activation when completing mental rotation tasks (Thomsen et al., 2000). In line with the fMRI literature, ERP studies have also shown sex differences in neural activity during mental rotation tasks. In particular, parietal lobe activity has been reported to be more symmetrically organized in women than in men, where activity is biased to the right hemisphere (Johnson, McKenzie, & Hamm, 2002; Rescher & Rappelsberger, 1999).

To date, no study has evaluated the relationship of mental rotation performance to the sexually dimorphic structure of the human parietal lobe. Given that there are well-documented sex-related differences in parietal lobe morphology and mental rotation performance, and that the parietal lobe has been implicated in performing mental rotations in fMRI, PET, ERP, and lesion literature, the purpose of this study is to examine sex differences in parietal lobe structure and relate these differences to performance on a mental rotation task.

2. Methods

2.1. Subjects

The study sample consisted of 76 ($n = 38$ female, $n = 38$ male) healthy, normal adult volunteers recruited via newspaper advertising. The two groups were equivalent in age, verbal IQ (VIQ), performance IQ (PIQ), full-scale IQ (FSIQ), years of education, and parental socioeconomic status (SES). Demographics of the sample are listed in Table 1. Subjects were screened by an experienced research assistant with a structured interview to assess their medical and psychiatric histories using an abbreviated version of the Comprehensive Assessment of Symptoms and History (Andreasen, Flaum, & Arndt, 1992). Subjects were excluded if by self report they had significant (requiring medical intervention) medical, neurological, or psychiatric illness including alcohol and substance abuse. IQ measures were obtained using the Wechsler adult intelligence scale-revised (WAIS-R), which was given as part of a cognitive testing battery. Handedness was determined quantitatively by use of a handedness scale developed by Benton (1967). All subjects, except two (one left-handed male, one mix-handed male), were right-handed and all subjects were Caucasian. Neuropsychological testing and imaging were completed on the same day, in the morning and in the afternoon, respectively. All subjects signed informed consent prior to participation. The protocol used was approved by the local institutional review board. The current sample overlaps substantially with our previous publication on sex differences in brain morphology (Nopoulos, Flaum, O'Leary, & Andreasen, 2000) $n = 32$ females and $n = 28$ males in are both samples.

Table 1
Demographics

	Women ($N = 38$)		Men ($N = 38$)		p^*
	Mean (*SD*)	Range	Mean (*SD*)	Range	
Age	26.1 (6.8)	19–47	27.2 (7.5)	18–47	.512[a]
VIQ	106.1 (9.1)	86–126	109.1 (12.1)	84–126	.218[a]
PIQ	115.6 (12.0)	87–143	111.0 (11.5)	87–136	.092[a]
FSIQ	111.4 (9.9)	91–129	111.0 (11.8)	86–130	.892[a]
Education (years)	14.9 (1.3)[c]	12–17	14.3 (1.9)	9–18	.107[b]
Parental SES	2.86 (0.5)[c]	2–4	2.68 (0.5)	2–4	.145[b]
Height (cm)	163.5 (8.0)[c]	150–180	178.5 (5.9)	168–193	<.0005[b]

Mean values, standard deviations, and ranges for demographic variables of the sample separated by sex. *p*-Values from independent samples *t*-tests to assess differences between men and women are reported. Parental SES is measured on a scale from 1 to 4.
[a] df = 74.
[b] df = 73.
[c] $N = 37$.

2.2. MRI acquisition

Images were obtained on a 1.5 Tesla GE Signa MR scanner. Three different sequences were acquired for each subject. T1 weighted images, using a spoiled grass sequence, were acquired with the following parameters: 1.5 mm coronal slices, 40° flip angle, TR = 24 ms, TE = 5 ms, NEX = 2, FOV = 26 cm, and a 256×192 matrix. The PD and T2 weighted images were acquired with the following parameters: 3.0 mm coronal slices, TE = 36 ms (for PD), or TE = 96 ms (for T2), TR = 3000 ms, NEX = 1, FOV = 26 cm, 256×192 matrix and an echo train length = 8. Processing of the images after acquisition was done using a locally developed family of software programs called BRAINS2 (acronym for Brain Research: Analysis of Images, Networks, and Systems). Details of the image analysis are published elsewhere (Magnotta et al., 2002). Briefly, a three-dimensional data set is created, and the images are realigned, resampled, and the Talairach Atlas is warped onto the brain (Talairach & Tournoux, 1988).

2.3. Brain volume measures

Within the stereotactic space, boxes were assigned to specific brain regions. Intracranial volume was subdivided into brain tissue and cerebral spinal fluid. Brain tissue was subdivided into the cerebrum and cerebellum. Measures of cerebral tissue volume thus exclude cerebellar tissue. The cerebrum was then divided further into its four lobes. Volumes of tissue were obtained from each region in an automated fashion. Automated measures obtained using a stereotactically based method have been reported by our laboratory and others to be efficient and accurate for cerebral lobe measures (Andreasen et al., 1996; Collins, Neelin, Peters, & Evans, 1994).

2.4. Surface anatomy

This method is described in detail by Magnotta et al. (1999). To summarize here, the data were initially segmented using the method described above. The segmented image was then processed using our BRAINSURF program which extracts a triangle-based polygonal model of an iso-surface, representing the parametric center of the GM tissue class. Surface area is calculated as the sum total of the surface in a given region.

2.5. Mental rotations test

The mental rotations test (MRT) developed by Vandenburg and Kuse (1978) was completed by participants as part of a neuropsychological battery. The MRT uses two-dimensional renderings of three-dimensional objects initially developed by Shepard and Metzler (1971). This test consists of 20 items, each item containing one target figure presented to the far left of each item and four choice figures presented to the right (see Fig. 1). Participants were to identify the correct alternatives, which were identical to the target in form but displayed in a rotated position. Among the four choice figures, there are two correct alternatives and two incorrect alternatives. The MRT was scored with a possible total score of 40 (20 items, each with two correct responses). Participants were given 10 min to complete the task, yielding a measure of the total num-