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Individual Differences in Regional Gray Matter Volumes According to the Cognitive Style of Young Adults

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Abstract

Extant research has proposed that the Object-Spatial-Verbal cognitive style can elucidate individual differences in the preference for modality-specific information. However, no studies have yet ascertained whether this type of information processing evinces structural correlations in the brain. Therefore, the current study used voxel-based morphometry (VBM) analyses to investigate individual differences in gray matter volumes based on the Object-Spatial-Verbal cognitive style. For this purpose, ninety healthy young adults were recruited to participate in the study. They were administered the Korean version of the Object-Spatial-Verbal cognitive style questionnaire, and their anatomical brain images were scanned. The VBM results demonstrated that the participants' verbal scores were positively correlated with regional gray matter volumes (rGMVs) in the right superior temporal sulcus/superior temporal gyrus, the bilateral parahippocampal gyrus/fusiform gyrus, and the left inferior temporal gyrus. In addition, the rGMVs in these regions were negatively correlated with the relative spatial preference scores obtained by individual participants. The findings of the investigation provide anatomical evidence that the verbal cognitive style could be decidedly relevant to higher-level language processing, but not to basic language processing.

Key words: Cognitive Style, Superior Temporal Gyrus, Regional Gray Matter Volumes, Voxel-Based Morphometry, Higher-Level Language Processing

1. Introduction

Cognitive style is defined as a preference, attitude, or habitual strategy related to how an individual processes environmental information (Messick, 1976). One of the frequently used cognitive styles is the visual-verbal dimension (e.g., Pavio, 1971) that proposes the importance of preferences in Visual versus Verbal dimensions in information processing. However, based on considerable neuroscientific findings that visual processing is divided into object and spatial dimensions (e.g., Farah, Hammond, Levine, & Calvanio, 1988), the Object-Spatial-Verbal dimension of cognitive style (Blazhenkova & Kozhevnikov, 2009) has been relatively recently proposed. According to this model, object style is characterized by a preference for colorful and pictorial information processing, whereas spatial style is defined as a preference for information

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related to location and spatial relationships. Meanwhile, verbal style is characterized by a preference for verbal processing.

Meanwhile, there is an increasing body of evidence for neural plasticity, as structural changes (e.g., training-induced gray matter increases) have been observed after programmed learning periods (e.g., Draganski et al., 2004). Moreover, according to neuroanatomical studies comparing amateurs with experts in their own fields, experts have larger gray matter volumes in expertise-relevant areas than non-experts and the size of these areas was positively correlated with the amount of experience in their field (e.g., Gaser & Schlaug, 2003).

Increased gray matter volumes are reflective of the growth of synapses with age and/or learning (Giedd et al., 1999). Considering the fact that cognitive style is reflective of individuals' habitual cognitive processes, it is expected that there might be individuals' structural differences in the brain according to cognitive style. Namely, larger regional gray matter volumes (rGMVs) in the regions associated with certain types of cognitive style could be interpreted that more frequent use of the resources in those areas. Indeed, some recent studies have investigated individual structural differences according to the different dimensions of cognitive style (e.g., field dependence/independence, or systemizing/ empathizing) using voxel-based morphometry (VBM) (Lai et al., 2012; Sassa et al., 2012).

Recently, a neuroimaging study provided a functional evidence that the cognitive control processing is associated with individuals' preference of cognitive style by using the Object-Spatial-Verbal cognitive style (Shin & Kim, 2015). In this study, using a version of the color-word Stroop task, which requires resolution processing of the conflict between the color of the word (i.e., color component; target) and the meaning of the word (i.e., verbal component; distracter), they observed that participants who preferred to process verbal material (i.e., verbalizers) exhibited higher neural conflict adaptation in cognitive control regions (e.g., left dorsolateral prefrontal cortex, fusiform gyrus, and precuneus) than others. Based on these findings, they concluded that the preference for the component of distracter is related to neural activity during cognitive control processing and suggested that individual differences in cognitive control are partly accounted for by preference for cognitive style. Similarly, functional imaging studies suggested that cognitive style is associated with individual's top-down modulation for modality-specific cognitive processing (Kraemer, Hamilton, Messing, DeSantis, & Thompson-Schill, 2014; Kraemer, Rosenberg, & Thompson-Schill, 2009).

However, it is still unknown whether the Object-Spatial-Verbal cognitive style is also related to anatomical differences in the brain although this cognitive style was characterized based on the neuroscientific evidence that visual processing is divided into object and spatial dimensions. Therefore, the current study sought to explore brain regions in which rGMVs correlated with cognitive style in the Object-Spatial-Verbal dimension using VBM analysis. In particular, we focused on rGMV because rGMV in certain brain region is closely associated with cognitive domains such as verbal and spatial abilities (Haier et al., 2004; Colom et al., 2009) and the Object-Spatial-Verbal cognitive style was originally developed by domain specific cognitive processes (Blazhenkova & Kozhevnikov, 2009).

2. METHODS

2.1. Participants

Ninety healthy young adult subjects (43 females and 47 males) aged between 18 and 28 years (M = 22.28, SD = 2.54) participated in this study. All participants provided written informed consent approved by the Brain Science Research Center at Korea Advanced Institute of Science and Technology (KAIST) in Daejeon, South Korea. None of the participants reported a history of neurological or psychiatric illness.

2.2. Materials and procedure

The Korean version of the Object-Spatial-Verbal cognitive style questionnaire (OSIVQ: Blazhenkova & Kozhevnikov, 2009; Shin & Kim, 2013) was administered to measure individual preference for object, spatial, and verbal cognitive styles before scanning. For example, the statement, “I have difficulty expressing myself in writing,” was included in order to measure verbal preference. A total of 29 statements were included and each of them was presented as a 5-point Likert scale. The scores for three different cognitive styles were calculated by averaging items assigned to those factors.

2.3. Imaging acquisition

Imaging data were acquired on a 3T Siemens Verio scanner at the fMRI Center at KAIST in Daejeon, South Korea. T1-weighted structural images were collected from all the subjects using magnetization-prepared rapid gradient-echo (MP-RAGE) sequences (repetition time (TR) = 1,800 ms; echo time (TE) = 2.52 ms; inversion time (TI) = 1,100 ms; flip angle (FA) = 9°; field of view (FOV) = 256 × 256 mm; resolution = 1 mm; sagittal partitions).

2.4. VBM preprocessing and analysis

ImagingT1-weighted high-resolution structural image data were preprocessed and analyzed using the SPM8 (Statistical Parametric Mapping; Wellcome Department of Cognitive Neurology, London, UK; http://www.fil.ion.ucl.ac.uk/spm) on MATLAB (MathWorks, Natick, MA).

First, using SPM8’s New Segment option, all subjects’ structural images were segmented into gray matter (GM), white matter (WM), and cerebral spinal fluid (CSF). Subsequently, these images were transformed into the template space created by integrating all the subjects’ T1 images and then normalized into the standard Montreal Neurological Institute (MNI) space using Diffeomorphic Anatomical Registration Through Exponentiated Lie algebra (DARTEL). Finally, the normalized GM images (1.5 mm3 isotropic voxels) were spatially smoothed with an 8 mm full-width-half-maximum (FWHM) Gaussian kernel to reduce inter-subject variability (Ashburner, 2007). Additionally, an absolute threshold mask of 0.2 was used to avoid any possible overlapping edge effect between the GM and WM.

Statistical analyses were conducted on the preprocessed GM images as follows, in order to identify brain regions associated with cognitive style: First, multiple regression analyses were conducted to identify the regions where rGMV was correlated with each of the OSIVQ scores (i.e., object, spatial and verbal scores) at the whole-brain level. Gender was added as a covariate of no interest in the model for each analysis. The statistical thresholds were set to $p < 0.05$ at the cluster level (with a threshold $p < 0.001$ for the voxel level and a minimum cluster size of 294 voxels) on the basis of AFNI’s AlphaSim Monte Carlo simulation(http://afni.nimh.nih.gov/afni/doc/manual/AlphaSim).

Additionally, since spatial and verbal scores showed a negative correlation coefficient (see RESULTS), regions showing any relationship with verbal scores were also correlated with the relative preference scores for verbal and spatial styles as a form of follow-up

Table 1. Correlation between cognitive styles and descriptive statistics on the Object-Spatial-Verbal cognitive style questionnaire (OSIVQ; n = 90)

	Verbal	Spatial	Object	M	SD	Min	Max
Verbal	-			3.50	0.64	1.64	4.73
Spatial	−.511**	-		3.03	0.91	1.29	4.86
Object	.010	−.087	-	2.59	0.57	1.45	4.82

** p<.01

analyses. In order to explore whether relative preference scores (i.e., scores showing selective preference for a certain cognitive style) were related with rGMVs extracted from each ROIs, relative preference scores for verbal and spatial styles were first calculated and correlated with rGMVs extracted from each ROIs for individuals. For these analyses, the scores on each style were normalized by the Min-Max method, which results in that the range of original values from minimum to maximum are mapped to the range of 0 to 1. This procedure was conducted because participants' scores on object, verbal, and spatial styles measured by OSIVQ were different in their means and ranges as shown in Table 1. Then these scores were submitted to calculate their relative preference scores on each style by subtracting the average of the other scores (e.g., for the relative verbal preference score, the verbal score was subtracted by the average of object and spatial scores).

3. RESULTS

First, the scores measured by OSIVQ were analyzed (Table 1). The scores of the object (M = 2.59, SD = 0.57), spatial (M = 3.03, SD = 0.91), and verbal cognitive styles (M = 3.50, SD = 0.64) were calculated by averaging measurements of the items assigned to those factors, and correlations between the scores were examined. The results showed that spatial and verbal scores were negatively correlated ($r = -0.511$, $p < 0.001$), but object scores were not correlated with other cognitive style scores (Table 1). In order to calculate the relative preference on verbal style compared to

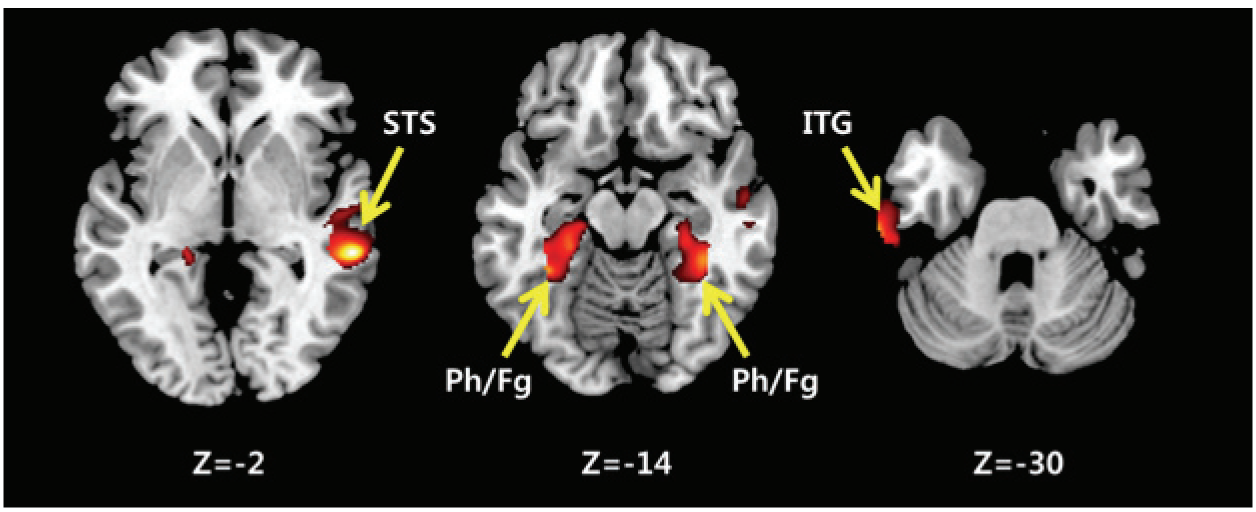

Fig. 1. Regions showing significant correlation coefficients between regional gray matter volumes (rGMVs) and verbal scores. The cluster-level threshold was adjusted to p < 0.05 using the AlphaSim Monte Carlo simulation. Regions of positive correlation are overlaid onto the Montreal Neurological Institute (MNI) template: STS, superior temporal sulcus; Ph/Fg, parahippocampal/fusiform gyrus; ITG, inferior temporal gyrus.

Table 2. Brain regions showing significant positive correlations between regional gray matter volume (rGMV) and the verbal score (n = 90)

Region	L/R	MNI coordinate			t-value	Cluster size
		X	Y	Z		
Superior temporal sulcus	R	57	-33	-2	5.40	2,020
Parahippocampal / fusiform gyri	L	-22	-34	-6	5.14	1,584
	R	38	-37	-12	4.57	1,116
Inferior temporal gyrus	L	-62	-24	-29	4.48	560

spatial style, the spatial scores were deducted from the verbal scores in individual data.

In order to identify rGMVs correlated with cognitive style scores, multiple regression analyses were separately conducted with each of the object, spatial and verbal scores, and gender as a nuisance variable. The results showed that four regions were positively correlated with verbal scores with a threshold of $p < 0.05$ at a cluster-corrected level (cluster size > 294 with a threshold of $p < 0.001$ at a voxel level) using the AlphaSim Monte Carlo simulation: right STS, bilateral Ph/Fg, and left ITG. Table 2 presents cluster details including their coordinates, statistics and sizes, Fig. 1 shows their anatomical locations, and the left panel of Fig. 2 shows scatter plots for these clusters. In contrast, no significant correlation between rGMV and spatial scores or between rGMV and object scores was found at the same statistical level.

Since spatial preference is known to be negatively correlated with verbal preference (Blazhenkova & Kozhevnikov, 2009; Jeon & Han, 2003; Kraemer et al., 2009) and the same relationship was found in the current study, rGMV values from the peak voxels of the four aforementioned regions were analyzed with the relative preference scores of spatial style. As shown in Fig. 2, individual relative spatial preference scores negatively correlated with rGMV values extracted from the right STS ($r = -0.324$, $p = 0.002$; the peak coordinate $x = 57$, $y = -33$, $z = -2$), left Ph/Fg ($r = -0.444$, $p < 0.001$; $x = -22$, $y = -34$, $z = -6$), right Ph/Fg ($r = -0.325$, $p = 0.002$; $x = 38$, $y = -37$, $z = -12$), and left ITG ($r = -0.227$, $p = 0.032$; $x = -65$, $y = -24$, $z = -29$). Note that the relationships between rGMVs and verbal scores are also presented in the left panel of Fig. 2 for the purpose of comparison between correlations of verbal and spatial scores with rGMV.

4. DISCUSSION

This study is the first attempt to reveal the relationship between rGMVs and an individual's preference for a certain type of cognitive style using the Object-Spatial-Verbal dimension of cognitive style. The analysis of the preference scores for three different cognitive styles measured by the OSIVQ indicated that only verbal and spatial scores were correlated. This is in line with the previous studies showing a negative relationship between the two preference styles (Blazhenkova & Kozhevnikov, 2009; Shin & Kim, 2013; 2015).

The VBM results showed that several cortical regions were correlated with verbal preference: as verbal scores increased, the gray matter volumes in the right STS, bilateral Ph/Fg, and left ITG also increased, whereas the rGMVs in the same regions were negatively correlated with relative spatial preference scores. Below we discuss these findings in detail and their implications suggesting that the structural differences in the above-reported regions are reflective of individual differences in language processes beyond the basic level.

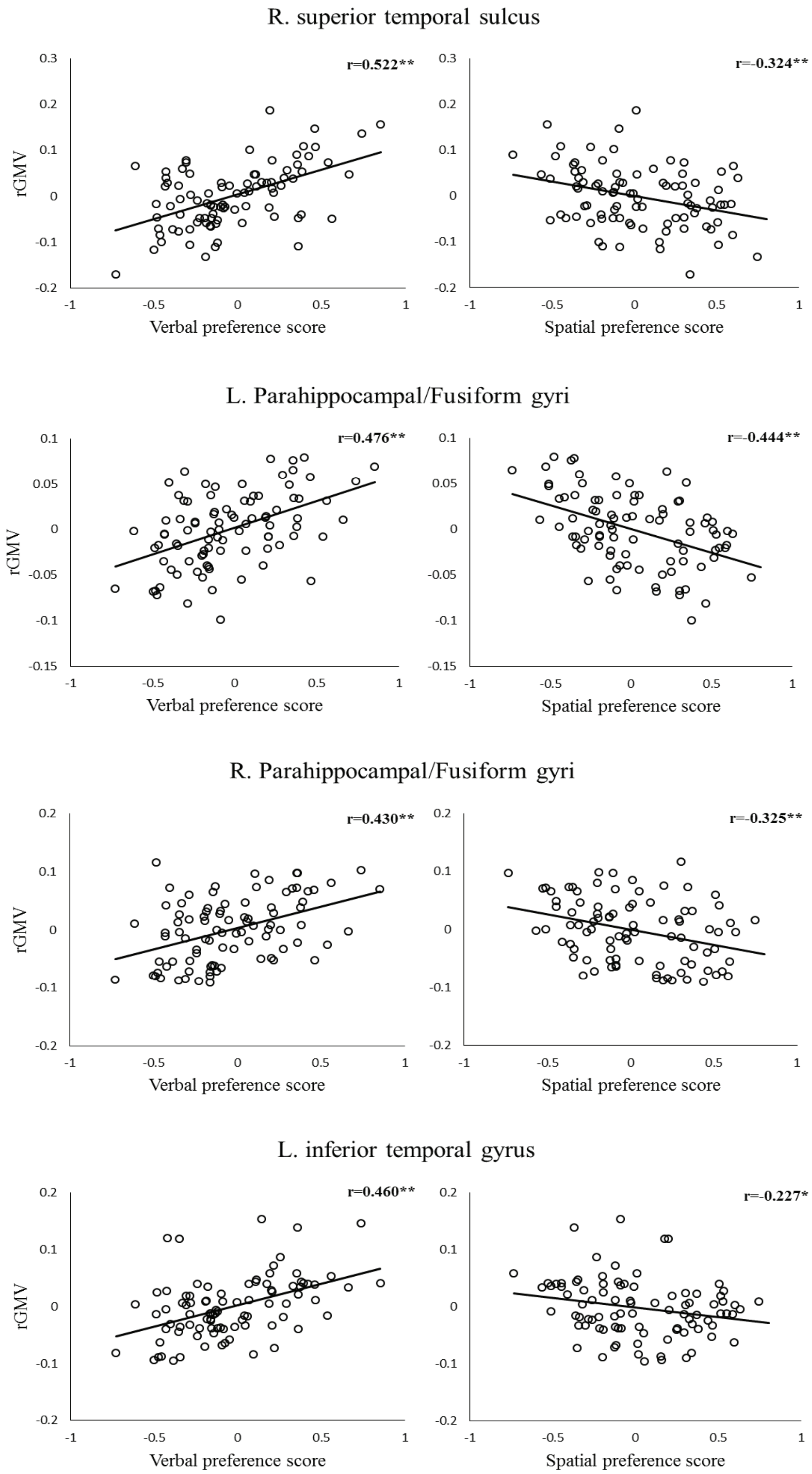

Fig. 2. Corelations between the regional gray matter volume (rGMV) values from the peak voxels of four regions showing significant relationship with the verbal scores, and the relative preference scores of verbal (left) and spatial cognitive style (right).

First, we observed a positive correlation between verbal preference and rGMV in the right STS/STG. A number of studies have reported that right temporal regions have an indispensable role in verbal processing. For instance, this area is involved in higher-level linguistic processes such as sentence-level prosody (Friederici, 2011), semantic processing (Kuperberg et al., 2000), comprehension of sentence and context (Vigneau et al., 2011), metaphor comprehension (Ferstl, Neumann, Bogler, & Von Cramon, 2008), and so on.

One might expect that verbal preference would be relevant to the rGMV in the left STS/STG (or Wernicke area), because this area is well-known for its engagement in fundamental language processing. However, in the current study, a relationship between verbal preference and rGMVs was found in the right STS/STG, not in the left site. Interestingly, the aforementioned roles of the right STS/STG suggest that the left STS/STG plays a primary role in verbal processing whereas the right STS/STG is engaged in higher-level language processing.

In line with the functional role of the right STS/STG in language processing, a number of studies of patients with damage to the right temporal lobe reported that these patients had difficulties in lingual processing at a higher level (Vigneau et al., 2011), while patients with damage to the left temporal lobe exhibited impaired language processing at various levels (for review, see Johns, Tooley, & Traxler, 2008). In a recent study, Mason and colleagues (2014) demonstrated that the activation of the right Wernicke area increased as the structural complexity in sentences increased and suggested that this area plays a compensatory role in higher-level language processes.

In keeping with the aforementioned findings, the current result indicates that verbal cognitive style is not relevant to individual differences in rGMVs of the left temporal areas, which plays an important role in rudimentary verbal/linguistic processing, but is closely related to those of right temporal areas, which is closely associated with supplementary verbal/linguistic processing. Thus, a potential hypothesis would be that an individual who prefers to process environmental information verbally, compared to a spatializer, would have continuously employed neural resources of the right temporal areas more often when a higher level of verbal processing (e.g., inferences and metaphors) was required, leading to the greater rGMVs. Consistently, previous studies have frequently suggested that processing of the metaphorical or inferential aspect of sentences are closely associated with neural activations in right temporal areas (Bottini et al., 1994; Kircher, Brammer, Andreu, Williams, & McGuire, 2001; Mason & Just, 2004).

Second, rGMVs in the bilateral parahippocampal gyrus and the anterior portion of the fusiform gyrus were positively correlated with verbal scores. Recent neurological studies demonstrated that bilateral Ph/Fg were co-activated during various language-related processes, such as local contextual processing (Chen & Li, 2013), narrative comprehension (Ferstl et al., 2008), lexico-semantic processing (Mion et al., 2010), and so on. Although the posterior portion of the fusiform gyrus has been reported to be involved in lower level language processing such as orthographic word form processing (Booth et al., 2002), in the current study, a significant correlation with verbal scores was found only in the anterior portion of the fusiform gyrus. Thus, we suggest that individual differences in verbal cognitive style may contribute to the differences in verbal processing at the semantic level, not at the lower perceptual level.

Third, rGMVs in the anterior part of the left ITG were also positively correlated with verbal cognitive style. As with the above mentioned areas, this region has been reported to be engaged in lexico-semantic processing (Kuperberg, Lakshmanan, Greve, & West, 2008). Interestingly, according to a resting metabolism study conducted on patients with semantic dementia (SD), the patients showed hypo-metabolism in the anterior part of the left ITG, whereas such reduction was absent in the posterior part (Nestor, Fryer, & Hodges, 2006). Given that the posterior part of the left ITG is often reported to be involved in language processing at perceptual levels such as word recognition and representation of the written forms of the words (Nobre, Allison, & McCarthy, 1994), the verbal scores' positive relationship only with the anterior part of the left ITG implies that the individual preference for verbal cognitive style is involved in language processing at the semantic level.

Although we found that some brain regions were anatomically correlated with the verbal cognitive style, it is unclear yet whether repeated use of verbal processing causes structural and/or functional differences in the related regions or vice versa. Additionally, in the present study, it is not clear why no regions were found to be relevant to the object/spatial cognitive styles. Therefore, future studies will be needed to address these questions.

In conclusion, the current study found that the difference between verbal and spatial cognitive style is related to individual difference in brain structures including the right STS/STG, bilateral Ph/Fg, and left ITG. Importantly, our findings provide anatomical evidence that verbal cognitive style is relevant to higher level language processing, but not to basic language processing. Therefore, we suggest that individual differences in verbal preference can be partly explained by structural differences in the cortical regions.

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