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An examination of orbitofrontal sulcogyral morphology in obsessive–compulsive disorder☆

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A R T I C L E I N F O

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A B S T R A C T

Obsessive–compulsive disorder (OCD) has been consistently associated with structural and functional alteration of the orbitofrontal cortex (OFC) and its subcortical connections. In exploring these alterations, a neurodevelopmental basis to OCD has been suggested. While some studies have examined outcomes of early cortical maturation processes, such as global cortical thickness and gyrification, no work has specifically examined the OFC. Within the OFC, three types of sulcogyral patterns have been identified as a result of variance in cortical folding. The distribution of these patterns has been found to differ in patients of various neuropsychiatric disorders relative to the general population, however no study has yet investigated this distribution in individuals with OCD. Eighty OCD patients and 78 healthy controls were evaluated using magnetic resonance imaging, with identification of the sulcogyral pattern based on the method of Chiavaras and Petrides (2000). While gross changes in OFC sulcogyral patterning did not distinguish OCD patients from healthy controls, expression of both the Type II and Type III patterns was significantly associated with increased OCD illness severity. This finding indicates that early neurodevelopmental factors may influence illness severity.

1. Introduction

Obsessive–compulsive disorder (OCD) is a disabling neuropsychiatric disorder that is characterized, as its name implies, by both obsessions and compulsions. Obsessions are mostly experienced as thoughts or urges that are often intrusive, negative and repetitive, and which lead to considerable anxiety or doubt. Compulsions are behaviors performed to neutralize the negative feelings associated with obsessions. These symptoms are time-consuming and cause marked distress and functional impairment (Ruscio et al., 2010). In about 75% of cases, symptoms emerge during childhood or early adolescence (Taylor, 2011) and frequently persist into adulthood. OCD has been consistently linked to alterations of cortico-striatal-thalamic circuits, with hypermetabolism in the orbitofrontal cortex (OFC) and its extended connections to the ventral striatum and thalamus notable using both PET and fMRI (Brennan and Rauch, 2017).

In functional brain imaging studies of OCD patients, hyperactivity of the OFC has been consistently observed both at rest and with symptom provocation. These findings have been extended to identifying structural hyperconnectivity of the extended OFC circuity (Piras et al., 2013; Harrison et al., 2009, 2013; see also Soriano-Mas and Harrison, 2017). There is also evidence to suggest structural alteration in OCD patients, including grey-matter volumetric alterations, altered patterns in tissue covariance, and shape deformation of the OFC-basal forebrain region

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(Piras et al., 2015; Pujol et al., 2004; Cardoner et al., 2007; Pujol et al., 2011; see also Boedhoe and van den Heuvel, 2017). In relation to some of these findings, a neurodevelopmental basis with an emphasis on late cortical maturation processes has been suggested (Pujol et al., 2011). Interestingly, only a few studies to date have explored the contribution of potential earlier neurodevelopmental changes in OCD, which may include changes predating symptom onset and potentially constitute biological risk markers (Suñol et al., 2018). These studies have predominantly measured gyrification index (Rus et al., 2017; Fan et al., 2012; Venkatasubramanian et al., 2012), and have revealed heterogeneous findings.

One such marker of early brain structural development relates to its sulcogyral patterning, which is established shortly after birth and remains stable throughout life (Chi et al., 1977). This patterning is assumed to have a strong genetic foundation (Im et al., 2011). These findings suggest that examinations of sulcogyral morphology may be less affected by environmental influences, exposure to medication, and comorbid conditions, which have been linked to some of the inconsistencies observed in structural neuroimaging studies of OCD patients (Boedhoe et al., 2017; Piras et al., 2015). In characterizing the orbitofrontal cortex in terms of its sulcogyral patterning, Chiavaras and Petrides (2000) identified three major types present in the general population. Type I was the most common, occurring in 56% of hemispheres, and was seen more often in the right hemisphere. The Type II pattern was observed in 30% of hemispheres, and was more common in the left hemisphere, and the Type III pattern was observed in only 14% of hemispheres, also more common in the left hemisphere.

Based on this work, several studies have since examined changes in sulcogyral morphology in other neuropsychiatric disorders, such as schizophrenia. In the first study to do so, Nakamura et al. (2007) observed decreased occurrence of Type I and increased occurrence of Type III in schizophrenia patients relative to healthy controls, a finding which has since been replicated (Nishikawa et al., 2016). Additionally, the asymmetry described by Chiavaras and Petrides (2000) was not present in patients with schizophrenia (Nakamura et al., 2007). Furthermore, patients with Type III expression in any hemisphere showed more severe symptoms, whereas patients with Type I in any hemisphere experienced milder symptoms. Other studies have additionally implicated Type II as a potential risk marker for schizophrenia (Cropley et al., 2015; Isomura et al., 2017) and first episode psychosis (Bartholomeusz et al., 2013). A study examining the relationship between OFC pattern type and schizotypy in a genetically 'at-risk of psychosis' population also demonstrated that abnormal expression of OFC types are present even before the individual develops symptoms (Chakirova et al., 2010), a finding which has since been replicated and points to the protective effect of possessing Type I in the right hemisphere in reducing the likelihood of transitioning to psychosis (Lavoie et al., 2014).

This method of exploring sulcogyral morphology in the OFC has also been extended to other psychiatric disorders. In high-functioning autism spectrum disorder (ASD), it has been found that there is increased occurrence of Type III in both hemispheres and reduced occurrence of Type I in the right hemisphere in patients with ASD compared to healthy controls (Watanabe et al., 2014). Similarly, within the left hemisphere the occurrence of Type I was reduced and Type III increased for patients with bipolar disorder (Patti and Troiani, 2018). This has led to the hypothesis that atypical OFC sulcogyral patterns may confer predisposition to psychiatric disorders generally (Patti and Troiani, 2018).

The aim of this study is to explore whether differences in OFC sulcogyral pattern distribution distinguish OCD patients from healthy controls, and therefore potentially implicate a role for early neurodevelopmental factors in the etiology of this disorder. We hypothesized that there would be significant differences between groups, and that the Type I sulcogyral folding pattern would be less common in the OCD group. Relatedly, we hypothesized that the Type I pattern might also be associated with reduced symptom severity in OCD patients. As secondary aims, we investigated whether sulcogyral patterns were associated with comorbid depression and anxiety symptoms, which frequently co-occur in OCD patients. We also investigated whether there was an association between sulcogyral type and symptom dimensions.

2. Methods

2.1. Participants

Eighty adult outpatients were recruited from the Obsessive–Compulsive Disorders Unit of the University Hospital of Bellvitge, Barcelona, Spain. Patients satisfied DSM-IV diagnostic criteria for OCD for at least one year prior to the study. Diagnosis was confirmed for each participant by two experienced psychiatrists through two separate interviews conducted one month apart using the Structured Clinical Interview for DSM-IV Axis I Disorder. The severity of OCD symptoms was assessed using the clinical version of the Yale-Brown Obsessive Compulsive Scale (Y-BOCS; Goodman et al., 1989), and the specific symptom profile of each patient was assessed with the Y-BOCS Symptom Checklist (Goodman et al., 1989). For the OCD group, comorbid non-psychotic mood and anxiety disorders were not considered to be exclusion criteria provided that OCD was the primary diagnosis and the reason that patients sought treatment. Depressive symptoms were measured with the Hamilton Depression Rating Scale (HDRS; Hamilton, 1960), and level of general clinical anxiety was scored with the Hamilton Anxiety Rating Scale (HARS; Hamilton, 1959). All patients on medication were taking stable doses for at least three months prior to scanning (see Supplementary Table 1 for a description of medications taken).

Seventy-eight healthy control participants (of similar age and gender distribution to the OCD group) were recruited from the same sociodemographic environment. Prior to inclusion in the sample, each control participant underwent the Structured Clinical Interview for DSM-IV (non-patient version) to exclude presence or past history of any psychiatric disorder.

General exclusion criteria for both OCD and control participants included the presence or past history of substance abuse and/or dependence (excluding nicotine), presence or past history of neurological disease, history of head injury involving loss of consciousness, history of psychotic episodes, experience with electroconvulsive therapy and/or neurosurgery, and contraindication to MRI scanning. All participants provided written consent to participate in the study after receiving a complete description of the protocol, which was approved by the Institutional Review Board of the University Hospital of Bellvitge. Data for 75 OCD participants and 61 control participants was included in a previous study (Subirà et al., 2013).

Table 1
Demographic and clinical data for the participants.

	OCD N = 80	Control N = 78
Age	M = 32.95 SD = 8.27	M = 33.13 SD = 10.09
Gender	Male = 42, Female = 38	Male = 42, Female = 36
Y-BOCS score	M = 26.57 SD = 5.23	
Symptom presence:		
hoarding	N = 26	
aggressive/checking	N = 62	
contamination/cleaning	N = 36	
symmetry/ordering	N = 34	
sexual/religious	N = 26	
HDRS score	M = 12.96 SD = 4.48	
HARS score	M = 15.91 SD = 5.59	

2.2. Image acquisition

All images were acquired with a 1.5T scanner (Signa Excite system, General Electric, Milwaukee, WI, USA) equipped with an eight-channel phased-array head coil. A high resolution T1-weighted anatomical image was obtained for each participant using a 3-dimensional fast spoiled gradient inversion-recovery prepared sequence with 130 contiguous slices in the axial plane (repetition time = 11.8 ms, echo time = 4.2 ms and flip angle = 90°, within a field of view of 30 cm, with a 256 × 256 pixel matrix and a slice thickness of 1.2 mm).

2.3. Image pre-processing and OFC sulcogyral pattern classification

Following a check for potential artifacts, skull-stripped brains were aligned along the anterior commissure-posterior commissure plane (using FLIRT rigid body position registration to the MNI template) and resampled to $1mm^3$. Images were classified on a LINUX workstation using Analyze 10.0 (Mayo Clinic). All sulci appearing on the orbital surface were identified and highlighted in the coronal section slice by slice using the tracing tool, and then viewed in axial and sagittal planes to aid classification of the OFC pattern type. Based on the previous classification protocol utilized by our lab (Bartholomeusz et al., 2013), a fissure was considered a sulcus when at least 4 mm long and 4 mm deep. For a sulcus to be continuous with another they had to be clearly connected in at least three slices.

OFC sulcogyral patterns were identified based on the classification technique described by Chiavaras and Petrides (2000). Sulcogyral patterns were classified into three types based on the continuity/discontinuity of the medial orbital sulcus (MOS) and lateral orbital sulcus (LOS) (see Fig. 1). For Type I the rostral and caudal portions of the MOS were disconnected while the rostral and caudal portions of the LOS were continuous, Type II is identified when both the MOS and LOS are continuous, and Type III was identified when rostral and caudal portions of both MOS and LOS were disconnected. In rare instances where the MOS was continuous but the LOS was disconnected, a Type III classification was given in line with our classification protocol (Bartholomeusz et al., 2009), given that the interrupted LOS is the distinguishing feature of the Type III pattern.

OFC pattern classification was performed by two expert raters, who were blind to both clinical and demographic information regarding the participants. Inter-rater reliability was performed on 10 randomly selected scans from the Melbourne Neuropsychiatry Centre database. Intra-class correlation coefficients (Cronbach's α) were 1.00 for both inter- and intra-rater reliability. A subset of 50 hemispheres that were deemed most difficult to classify from the current sample were reviewed (28 from the OCD group, 32 from the control group), with agreement between raters in 84% of cases.

2.4. Statistical analyses

Statistical analyses were performed with SPSS v.23 (SPSS Inc., Chicago, IL). Differences in demographical data between groups were analyzed using independent-samples *t*-tests (age) and $\chi2$ tests (gender).

To evaluate group differences in OFC pattern type distribution, $\chi2$ tests were applied independently for each hemisphere. Entered as the expected frequency of each sulcogyral type was the pattern distribution observed in the control group. Left-right asymmetry in pattern distribution was analyzed using a $\chi2$ test, where the distribution in one hemisphere was entered as the expected number in the other hemisphere. Sex differences were also analyzed in the same manner. The sulcogyral pattern distribution of the OCD and control groups were also compared to the pattern distributions for past studies in the area (Chiavaras and Petrides, 2000; Bartholomeusz et al., 2013; Chakirova et al., 2010; Cropley et al., 2013; Lavoie et al., 2014; Nakamura et al., 2007; Nishikawa et al., 2016; Patti and Troiani, 2018; Takayanagi et al., 2010; Uehara-Aoyama et al., 2011; Watanabe et al., 2014) using $\chi2$ tests. Post-calculations were performed to obtain relative frequencies to control for differing sample sizes when comparing across studies. Where a Type IV pattern was identified, this was collapsed with the Type III due to the interrupted LOS, consistent with previous studies and our classification protocol (Bartholomeusz et al., 2013; Patti and Troiani, 2018).

The relationship between across hemisphere OFC pattern type and several clinical variables were assessed by applying categorical regression analyses. The clinical variables included overall severity (Y-BOCS total score), severity of obsessions (Y-BOCS obsessions subscale score), severity of compulsions (Y-BOCS compulsions subscale score), scores on the HDRS and HARS, and age of onset. Each predictor in the model represented whether a particular participant had a certain sulcogyral type (Type I, Type II, Type III) present in at least one hemisphere. Years of education was also analyzed, as a general demographic variable in place of more optimal measures, such as socioeconomic status and cognitive function. Binary logistic regressions were applied to examine if the presence of any of the sulcogyral types predicted the symptom dimensions experienced by patients (hoarding, aggressive/checking, contamination/cleaning, symmetry/ordering, sexual/religious). For primary analyses, α was set at 0.05 uncorrected, in accordance with the methods of prior research (Bartholomeusz et al., 2013; Nakamura et al., 2007; Takayanagi et al., 2010).

3. Results

3.1. Participants

Groups did not differ significantly in either gender or age distribution. Table 1 summarizes the demographic and clinical characteristics of each group. One participant was excluded from the OCD group due to poor image quality.

3.2. Sulcogyral pattern type distribution

In both groups, the Type II pattern was the most uncommon across hemispheres, while the frequencies of Type I and Type III were similar. This finding was not altered with the exclusion of 50 difficult-to-classify hemispheres. Figs. 2 and 3 show the relative frequencies of the sulcogyral types across groups in the left and right hemispheres respectively. No between-group differences were observed in the frequency distribution of the three sulcogyral patterns in either hemisphere (χ^2 (2,

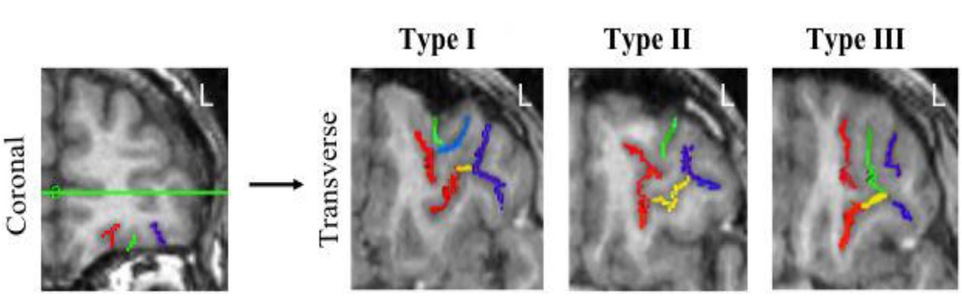

Fig. 1. Examples of the orbitofrontal sulcogyral patterns in the left hemisphere. Medial orbital sulcus (red), lateral orbital sulcus (purple), transverse orbital sulcus (yellow) and inferior orbital sulci (green, blue) are shown. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

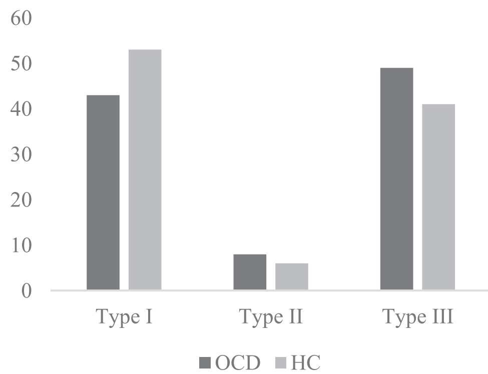

Fig. 2. Percentage of each sulcogyral type within the left hemisphere across groups. HC = healthy control.

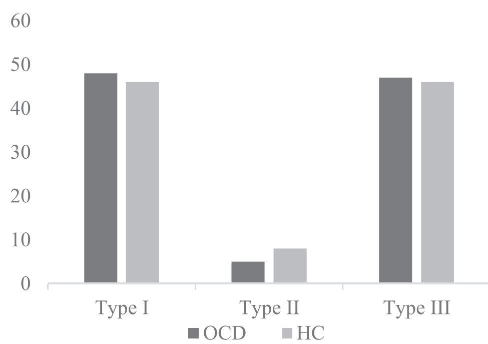

Fig. 3. Percentage of each sulcogyral type within the right hemisphere across groups. HC = healthy control.

Table 2
Proportion of orbitofrontal cortex sulcogyral types across hemispheres in clinical samples.

	Type I	Type II	Type III	Left/right asymmetry
Bartholomeusz et al. (2013) * N = 192	46%	27%	27%	Absent
Chakirova et al. (2010)*,[a] N = 68	43%	22%	35%	Absent
Cropley et al. (2015)* N = 178	53%	21.5%	25.5%	Present
Nakamura et al. (2007) * N = 100	41%	34%	25%	Absent
Nishikawa et al. (2016)[#],[b] N = 204	54%	10%	36%	Present
Patti and Troiani (2018)*,[c] N = 92	49%	24%	27%	Present
Takayanagi et al. (2010)* N = 84	39.5%	34.5%	26%	Absent
Watanabe et al. (2014)* N = 100	49%	27%	24%	Absent
Uehara-Aoyama et al. (2011)* N = 94	56%	29%	15%	Absent
Present study N = 158	46%	6%	48%	Absent

* Distribution differs significantly from present study using χ^2 tests at level of $p < 0.001$.
[#] Distribution differs significantly from present study using χ^2 tests at level of $p < 0.05$.
[a] First episode psychosis group.
[b] Schizophrenia group.
[c] Bipolar disorder group.

157) = 2.88, $p = 0.237$ left hemisphere; χ^2 (2, 157) = 0.78, $p = 0.676$ right hemisphere). There was no left-right asymmetry in either the OCD (χ^2 (2, 158) = 1.53, $p = 0.466$) or control groups (χ^2 (2, 156) = 1.31, $p = 0.521$). When comparing both the OCD group and the control group individually to previous studies, there were significant differences in terms of sulcogyral pattern distribution across hemispheres (see Table 2 for clinical samples and Table 3 for healthy controls. Note that where there were multiple groups within a study, the clinical sample used for the comparison is indicated).

Table 3
Proportion of orbitofrontal cortex sulcogyral types across hemispheres in healthy controls.

	Type I	Type II	Type III	Left/right asymmetry
Chiavaras and Petrides (2000)* N = 100	56%	30%	14%	Present
Bartholomeusz et al. (2013)* N = 146	60%	14.5%	25.5%	Present
Chakirova et al. (2010)* N = 72	57%	24%	19%	Absent
Cropley et al. (2015)* N = 174	56.5%	20.5%	23%	Present
Lavoie et al. (2014)* N = 116	55%	18%	27%	Absent
Nakamura et al. (2007)* N = 50	54%	32%	14%	Present
Nishikawa et al. (2016)* N = 168	67%	14%	19%	Present
Patti and Troiani (2018)* N = 106	70%	16%	14%	Present
Takayanagi et al. (2010) * N = 35	54.5%	32.5%	13%	Absent
Uehara-Aoyama et al. (2011) * N = 94	51%	34%	15%	Absent
Watanabe et al. (2014) * N = 110	56%	29%	15%	Absent
Present study N = 156	49%	7%	44%	Absent

* Distribution differs significantly from present study at level of $p < 0.001$.

There was also some evidence of sex differences in terms of the distribution of sulcogyral patterning (see Figs. 4 and 5). When collapsing across groups, females had significantly higher frequency of the Type III pattern and lower frequency of the Type I pattern in the left hemisphere only (χ^2 (2, 157) = 6.42, $p = 0.040$). However, given the low counts of Type II, sex differences within each group could not be accurately determined.

3.3. Functional outcomes

Within the OCD group, the Type II sulcogyral pattern was associated with increased total scores on the Y-BOCS (β = 5.49, $F = 2.38$, $p = 0.020$), which extended to the compulsions and obsessions subscales (β = 2.82, $F = 2.44$, $p = 0.017$, compulsions; β = 2.62, $F = 2.13$, $p = 0.036$, obsessions). The Type III sulcogyral pattern was also associated with increased total Y-BOCS scores ($\beta = 3.23$, $F = 2.20$, $p = 0.031$) and with increased scores on the obsessions subscale only (β = 1.79, $F = 2.28$, $p = 0.026$). The Type I pattern was associated

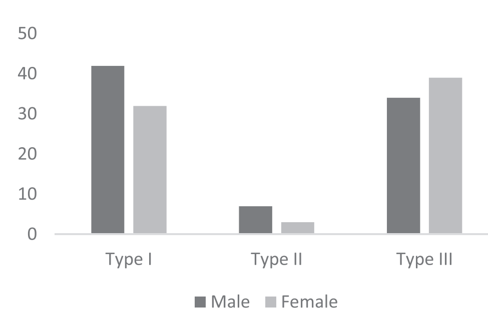

Fig. 4. Frequency of each sulcogyral type within the right hemisphere for each gender.

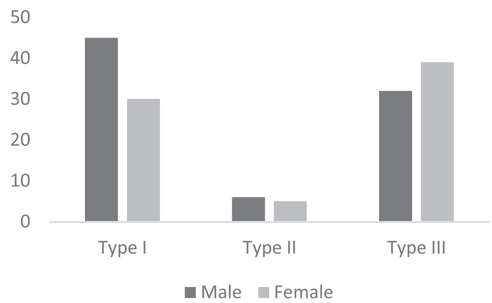

Fig. 5. Frequency of each sulcogyral type within the left hemisphere for each gender.

Table 4
Association between across hemisphere sulcogyral pattern type and clinical variables.

		β	F	p
Y-BOCS total	Type I	2.14	1.54	0.127
	Type II	5.49	2.38	0.020*
	Type III	3.23	2.20	0.031*
Y-BOCS obsessions subscale	Type I	0.88	1.19	0.239
	Type II	2.62	2.13	0.036
	Type III	1.79	2.28	0.026*
Y-BOCS compulsions subscale	Type I	1.26	1.82	0.073
	Type II	2.82	2.44	0.017*
	Type III	1.39	1.89	0.063
HARS	Type I	3.57	2.39	0.020
	Type II	1.96	0.78	0.435
	Type III	0.77	0.48	0.631
HDRS	Type I	2.11	1.75	0.085
	Type II	1.74	0.86	0.392
	Type III	0.83	0.65	0.519
Age of onset	Type I	0.05	0.03	0.980
	Type II	0.25	0.07	0.947
	Type III	-0.22	-0.09	0.926
Years of education	Type I	-0.05	0.00	0.948
	Type II	-0.34	0.07	0.793
	Type III	0.40	0.24	0.623

* Robust to exclusion of difficult-to-classify cases.

with increased HARS scores (β = 3.57, F = 2.39, p = 0.020). Finally, there was no significant association between sulcogyral pattern type and HDRS scores, age of onset or years of education. All associations are shown in Table 4. The findings regarding the association between Type II and total scores on the Y-BOCS and the compulsions subscale, and between Type III and total scores on the Y-BOCS and the obsessions subscale were robust to the exclusion of the 28 difficult-to-classify hemispheres.

Within the OCD group, only the model predicting presence of sexual/religious symptoms was significant (χ^2 = 9.39, p = 0.024). However, none of the predictor variables reached significance, see Table 5.

Table 5
Effect of presence of sulcogyral types on symptom dimension profile.

	Model χ^2	Model p	Predictor variables	Wald	p	Odds ratio
Hoarding	5.45	0.142	Type I	2.09	0.149	0.45
			Type II	0.64	0.422	2.25
			Type III	1.10	0.295	2.16
Aggressive/checking	0.81	0.848	Type I	0.66	0.416	0.54
			Type II	0.00	0.949	1.08
			Type III	0.05	0.827	0.85
Cleaning/contamination	4.13	0.247	Type I	2.21	0.137	2.33
			Type II	2.77	0.096	5.39
			Type III	0.66	0.415	1.63
Symmetry/ordering	2.50	0.475	Type I	1.33	0.250	1.92
			Type II	0.40	0.528	1.81
			Type III	0.15	0.696	0.79
Sexual/religious	9.39	0.024	Type I	1.39	0.238	2.04
			Type II	0.00	0.999	0.00
			Type III	2.37	0.124	2.82

4. Discussion

Contrary to our hypothesis, there were no significant differences in OFC sulcogyral morphology between OCD patients and healthy controls, nor was there an observed reduction in the frequency of Type I in the pattern distribution of OCD patients. Instead, we observed significant associations between the Type II and Type III patterns and OCD symptom severity, as well as between the Type I pattern and increased general anxiety.

The null finding regarding sulcogyral pattern differences between OCD patients and healthy controls in the present study might be attributed to the high incidence of the Type III sulcogyral type in both the control and OCD groups. Whereas previous studies have reported a frequency of the Type III pattern of no more than 36% across groups (see Tables 2 and 3) the present study reported a frequency of 48% in the OCD group and 44% in the control group. Given that this differs from most previous studies at the level of p < 0.001, this suggests that our sample is somewhat unique.

In explaining between-study variance in pattern frequencies across samples, it has been hypothesized that geographical location may be an important factor (Bartholomeusz et al., 2013; Lavoie et al., 2014; Cropley et al., 2015), with higher rates of Type III noted in southern hemisphere samples. However, the current sample was drawn from a northern hemisphere European population. Other studies conducted in the northern hemisphere, namely the UK (Chakirova et al., 2010), the USA (Nakamura et al., 2007) and Japan (Takayanagi et al., 2010; Watanabe et al., 2014) have described sulcogyral pattern distribution similar to that first described by Chiavaras and Petrides (2000). Other possible explanations for the difference of Type III incidence observed between samples are socioeconomic status, temperament, and cognitive function, all of which have been linked to the Type III pattern (Nakamura et al., 2007; Whittle et al., 2014). Prenatal factors are also likely to influence sulcogyral morphology, and should be investigated in future studies. Also, given the wide range of frequencies observed for both Type II and Type III in even control groups (see Table 3), more work into identifying a typical sulcogyral pattern distribution is recommended.

Despite there being no significant difference between OCD patients and healthy controls in terms of the distribution of sulcogyral pattern, both the Type II and Type III pattern were associated with severity of OCD symptoms. Possessing the Type II pattern in at least one hemisphere was associated with increased total severity of OCD symptoms and with increased severity of both obsessions and compulsions separately. Possession of the Type III pattern was also associated with increased severity of OCD symptoms, and was further associated with increased severity of obsessions alone. These results are consistent with prior studies of schizophrenia, where the Type II and Type III patterns have been associated with poorer outcome and more severe symptomatology. Although in our study, the Type I pattern was not observed to be associated with reduced severity of OCD symptoms, it neither was found to be associated with increased illness severity. The association between the Type I pattern and anxiety support prior work that although the Type I pattern may be protective in some cases, it may also confer vulnerability to other disorders (Whittle et al., 2014).

In examining specific symptom dimensions, there were no significant associations with sulcogyral pattern type. It is possible that our sample size may have precluded a definitive examination, and therefore future studies should continue to examine the possibility of an association. Potential limitations to this study include the spatial resolution of the imaging data (1.5T), and the possibility of human error in identifying sulci and classifying OFC sulcogyral type. It is also a limitation that sex differences within groups in terms of sulcogryal pattern distribution were not able to be accurately explored. Another limitation is that no measures for cognitive function or temperament were taken, so it could not be explored if these factors contributed to the unusual distribution of sulcogyral patterns observed. This study was also limited in that none of the results survived a more stringent Bonferroni correction, and so should be interpreted accordingly. It would also be interesting to examine other OCD-related disorders to confirm whether the observed association between Type II and Type III pattern frequency and symptom severity might represent a general transdiagnostic severity marker.

Whilst OFC sulcogyral pattern distribution did not distinguish OCD patients from healthy controls, OFC pattern type was associated with functional outcomes. In particular, the finding that the presence of Type II or Type III in either hemisphere is associated with overall increased symptom severity indicates that early neurodevelopmental factors may influence illness severity.

Contributors

Authors BJH and CS-M designed the study. Authors JMM and PA conducted the clinical interviews and confirmed the diagnoses. Authors HP and CB performed the OFC sulcogyral classifications. Author RD carried out the statistical analyses and wrote the first draft of the manuscript. All authors contributed to and have approved the manuscript.

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Conflicts of interest

None.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.pscychresns.2019.02.004.

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