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Neuroanatomical abnormalities in first episode psychosis across independent samples: a multi-centre mega-analysis

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Abstract

Background—Neuroanatomical abnormalities in first episode psychosis (FEP) tend to be subtle and widespread. The vast majority of previous studies have used small samples, and therefore may have been underpowered. In addition, most studies have examined participants at a single research site, and therefore the results may be specific to the local sample investigated. Consequently, the findings reported in the existing literature are highly heterogeneous. This study aimed to overcome these issues by testing for neuroanatomical abnormalities in individuals with FEP that are expressed consistently across several independent samples.

Methods—Structural Magnetic Resonance Imaging data were acquired from a total of 572 FEP and 502 age and gender comparable healthy controls (HC) at five sites. Voxel-based morphometry (VBM) was used to investigate differences in grey matter volume (GMV) between the two groups.

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Conflict of interest

None.

Statistical inferences were made at $p < 0.05$ after family-wise error correction for multiple comparisons.

Results—FEP showed a widespread pattern of decreased GMV in fronto-temporal, insular and occipital regions bilaterally; these decreases were not dependent on anti-psychotic medication. The region with the most pronounced decrease – gyrus rectus – was negatively correlated with severity of positive and negative symptoms.

Conclusions—This study identified a consistent pattern of fronto-temporal, insular and occipital abnormalities in five independent FEP samples; furthermore, the extent of these alterations is dependent on severity of symptoms and duration of illness. This provides evidence for reliable neuroanatomical alternations in FEP, expressed above and beyond site-related differences in anti-psychotic medication, scanning parameters and recruitment criteria.

Keywords

Neuroanatomy; multi-centre; voxel-based morphometry; mega-analysis; first episode psychosis

1 Introduction

Neuroanatomical abnormalities in schizophrenia have been well documented for the past four decades (Glahn *et al.* 2008; Bora *et al.* 2011). While the initial research was performed in patients with long-term schizophrenia (Ellison-Wright *et al.* 2008), more recent studies have focussed on individuals in the early stages of the illness, when the effects of chronicity (Olabi *et al.* 2011; Vita *et al.* 2012) and anti-psychotic medication (Radua *et al.* 2012; Vita *et al.* 2015; Shah *et al.* 2017) are minimal. The results of these studies, however, tend to be inconsistent from one investigation to another (Radua *et al.* 2012; Gao *et al.* 2017; Shah *et al.* 2017). For example, reports of insular abnormalities have been heterogeneous, with some studies reporting increased (Salgado-Pineda *et al.* 2003; Ren *et al.* 2013) and others decreased (Jayakumar *et al.* 2005; Chua *et al.* 2007; Venkatasubramanian, 2010) grey matter volume in this region. A possible explanation for these inconsistencies, is that most studies have used small sample sizes and therefore may have been under-powered. For example, in the most recent meta-analyses (Radua *et al.* 2012; Gao *et al.* 2017; Shah *et al.* 2017), out of a total of 37 studies included (after accounting for overlapping studies across meta-analyses) 20 had a total sample size of 60 or less. Studies with small sample sizes are likely to result in overestimates of effect size and low reproducibility due to low statistical power (Button *et al.* 2013); which suggests that some of these small studies may have suffered from increased risk of false positives. In addition to being under-powered, different studies have also varied significantly in terms of their methods such as recruitment criteria, imaging acquisition parameters, pre-processing and statistical analysis (Radua *et al.* 2012). Furthermore, the vast majority of studies have examined participants from a single research site, raising the possibility that the results might be specific to the characteristics of the local sample investigated.

To overcome some of these limitations, the ENIGMA consortium developed a standardized pipeline detailing data pre-processing and analysis procedures; once data is analysed, single-site results are pooled and summarized in a meta-analysis. This approach has led to

unprecedented sample sizes in schizophrenia research, with two recent studies of cortical abnormalities in 4,474 patients and 5,098 controls (van Erp *et al.* 2018), and subcortical changes in a smaller, albeit still impressive, sample of 2,028 patients and 2,540 controls (van Erp *et al.* 2016). However, although this approach mitigates some of the main limitations of traditional meta-analysis by reducing the heterogeneity of the pooled single-studies, findings still rely on reported results from individual studies, which may result in limited accuracy (Shah *et al.* 2017). Multi-centre mega-analyses, involving the preprocessing and integration of data from independent studies in one single statistical analysis, provide an opportunity to overcome this limitation. Gupta *et al.* (2015) analysed neuroanatomical abnormalities in the first mega-analysis in schizophrenia in a sample comprised of 784 individuals with established schizophrenia and 936 healthy controls collected from 23 sites. More recently, Rozycki *et al.* (2017) analysed data from 5 sites totalling 448 healthy controls and 387 patients with chronic schizophrenia. Similar mega-analytic efforts focussed on the initial stages of the illness, when the effects of confounders are minimal, are still non-existent and evidence is still reliant on small to modest sized studies (Shah *et al.*, 2017; Gao *et al.*, 2018).

In light of the limitations of the existing literature, the aim of this study was to use a multi-centre mega-analytic approach to test for neuroanatomical changes in FEP that are consistent across independent samples. Based on the findings of the recent meta-analyses (Radua *et al.* 2012; Gao *et al.* 2017; Shah *et al.* 2017), we hypothesize that i) patients would show grey matter volume decrease in a distributed bilateral network including fronto-temporal and insular areas, consistently across the five independent samples; ii) given previous reports of symptom-dependent neuroanatomical alterations in psychosis (Fusar-Poli *et al.*, 2012; Tang *et al.*, 2012), these decreases would be more pronounced in patients with more severe symptoms; and iii) consistent with existing evidence of progressive neuroanatomical changes in psychosis (Olabi *et al.* 2011; Vita *et al.* 2012), these decreases would be more pronounced in patients with longer duration of illness.

2 Methods

2.1 Subjects

A total of 1074 participants were included in the analysis. The total sample comprised of data collected from FEP patients and healthy controls (HC) recruited as part as five independent studies, from four sites, all of which were previously published: Chengdu (China) (Gong *et al.* 2015), London (England) (GAP study; Di Forti *et al.* 2009) Santander (Spain) (PAFIP study; Pelayo-Terán *et al.* 2008) and Utrecht (The Netherlands) (GROUP study; Korver *et al.* 2012). Below is a description of the recruitment criteria for each study. All patients were experiencing their first psychotic episode, defined as the first manifestation of psychotic symptoms meeting criteria for a psychotic disorder, as specified by the DSM-IV (APA, 2000) or ICD-10 (WHO, 2004). For each of the 5 sites, ethical approval was granted from the relevant Ethics Committees, and written informed consent was obtained from all participants. Demographic and clinical data for patients and healthy controls within each site are summarized in Table 1.

Site 1: Chengdu, China—First episode patients were recruited from the West China Hospital of Sichuan University, Chengdu, China as part of a wider study of psychiatric disorders Diagnosis. Diagnosis for first episode of schizophrenia was determined by the consensus of two clinical psychiatrists using the Structured Interview for the DSM-IV Axis I Disorder (SCID) (First *et al.* 1997). At the time of scanning, all patients were medication-naïve. Healthy controls were recruited by poster advertisement and screened using the SCID-I to confirm the lifetime absence of psychiatric disorders, as well as interviewed and subsequently excluded if they had any known history of psychiatric illness in first-degree relatives. Participants were excluded if they met any of the following criteria: (i) history of drug or alcohol abuse, (ii) pregnancy, and (iii) any physical illness such as hepatitis, cardiovascular disease, or neurological disorder, as assessed by interview and review of medical records.

Site 2: London, England—Participants were recruited from the South London and Maudsley Foundation Trust and scanned at the Institute of Psychiatry, Psychology and Neuroscience. All patients meeting ICD-10 criteria for a diagnosis of psychosis (codes F20–F29 and F30–F33) (World Health Organization, 2004) were invited to participate in the study; patients with a diagnosis of organic psychosis were later excluded. Healthy controls were recruited through local advertisement from the same geographical areas as patients. A screening tool (Psychosis Screening Questionnaire; Bebbington & Nayani 1995) was used to exclude the presence of psychotic symptomatology or a history of psychotic illness in controls. Additional exclusion criteria for all participants included learning disabilities (based as an IQ<70), current or past neurological illness, brain injury with loss of consciousness for more than 1 hour and suspected or confirmed pregnancy.

Sites 3 and 4: Santander A and B, Spain—Data from Santander A and Santander B were acquired as part of the same large prospective longitudinal study on first non-affective episode psychosis in the autonomous community of Cantabria, although with two different scanners. Individuals with FEP were recruited from both inpatient units and community mental health care centres. Patients were included if they met the following criteria: 1) age 15–60 years; 2) DSM-IV criteria for a principal diagnosis of schizophrenia, schizophreniform disorder, schizoaffective disorder, brief reactive psychosis, or not otherwise specified psychosis; and 3) no prior treatment with anti-psychotic medication or, if previously treated, a total life time of adequate anti-psychotic treatment of less than 6 weeks. Patients with DSM-IV diagnoses of mental retardation or substance dependence (except nicotine dependence) were excluded. Age and gender matched healthy controls were recruited from the community through advertisements and were screened for current or past history of psychiatric, mental retardation, neurological or general medical illnesses, including substance dependence and significant loss of consciousness, as determined by using an abbreviated version of the Comprehensive Assessment of Symptoms and History (CASH) (Andreasen, Flaum and Arndt, 1992). The absence of psychosis in first-degree relatives was confirmed by clinical records and family interview.

Site 5: Utrecht, The Netherlands—Patients were identified through clinicians working in regional psychosis departments or academic centres and were included if they met the

following criteria: 1) age range of 16 to 50 years; 2) a diagnosis of non-affective psychotic disorder according to the DSM-IV; 3) good command of the Dutch language; and 4) able and willing to give written informed consent. Controls were selected through a system of random mailings to addresses in the catchment areas of the cases and were included if the following criteria were met: 1) age range of 16 and 50 years, 2) no lifetime psychotic disorder, 3) no first-degree family member with a lifetime psychotic disorder, 4) good command of the Dutch language, and (5) able and willing to give written informed consent.

2.2 Magnetic Resonance Imaging (MRI) data acquisition

At all 5 sites, volumetric MRIs were acquired using a T1-weighted protocol. At three sites, the scanner field strength was 3T, and at 2 sites it was 1.5T. The details of the MRI acquisition sequence for each site can be found in the supplementary materials sTable 1.

2.3 Data analysis

2.3.1 Socio-demographic and clinical parameters—Differences between FEP and HC in gender, age and total intra-cranial volume (TIV) were assessed with a chi-square and independent-sample t-test for categorical and continuous data respectively, using SPSS v24.

2.3.2 Pre-processing—From the initial pool of 1249 images made available, 21 were excluded due to scanner artefacts and gross anatomical abnormalities, 71 due to excessive noise and a further 83 were excluded to keep the maximum and minimum age (18-55) the same across all sites. Differences in grey matter volume (GMV) between HC and FEP were examined using voxel-based morphometry, as implemented in SPM12 software (<http://www.fil.ion.ucl.ac.uk/spm/software/spm12/>) running under MATLAB 9 (The MathWorks, Inc, Natick, Massachusetts) (Ashburner and Friston, 2005). The following steps were followed for the pre-processing of each site: (1) checking for scanner artefacts and gross anatomical abnormalities for each subject; (2) setting the anterior commissure as the origin of the stereotaxic space and reorienting the image along the anterior commissure-posterior commissure (AC-PC) line; and (3) segmenting the image into grey matter, white matter and CSF maps. Next, all available images were used to create a study-specific template as implemented by the DARTEL (diffeomorphic anatomical registration using exponentiated lie algebra) toolbox (Ashburner, 2007). This procedure warps the grey matter and white matter partitions into a new study-specific reference space representing an average of all the subjects included in the analysis, thus maximizing accuracy and sensitivity (Yassa and Stark, 2009). Finally, GMV maps were normalized to the Montreal Neurological Institute MNI template and subsequently smoothed with an 8mm Gaussian filter. A “modulation step” was also included in the normalization step to preserve the information about the absolute grey matter values (Mechelli *et al.* 2005). The final smoothed, modulated, normalized data were used for the statistical analysis.

To assess the reliability of our findings, the analysis pipeline described above was replicated using: 1) CAT12 toolbox (<http://dbm.neuro.uni-jena.de/cat/>), 2) a template built with a homogeneous (equal number of patients and controls across sites) sub-sample 3) different size kernels for smoothing. Results are shown in the supplementary materials.

2.3.3 Statistical analysis—Statistical analysis was carried out using an analysis of variance (ANCOVA), with diagnostic group and scanning site as factors, resulting in 10 experimental groups. Age and gender were included as covariates of no interest. The option of proportional scaling was selected to remove confounding driven by global differences. Neuroanatomical alterations in patients with FEP relative to HC consistent across the five datasets were identified using the “inclusive masking” option as implemented in SPM software. This option allowed us to test for voxels which showed (i) an overall statistically significant difference between patients and healthy controls across all sites ($p < 0.05$ FWE corrected) and (ii) at least a strong trend at each site ($p < 0.05$ uncorrected). Specifically, this consisted on the following steps in SPM: i) comparing all FEP against all HC at $p < 0.05$ FWE corrected using an overall main contrast - FEP_{all sites} vs HC_{all sites} (e.g. FEP_{all sites} < HC_{all sites}), ii) overlaying this contrast with a second set of five FEP vs HC contrasts, one for each site (e.g. FEP_{site 1} < HC_{site 1}) at $p < 0.05$ uncorrected each, and finally iii) identifying voxels of increased/decreased GMV in FEP relative to HC that survived both the overall and the site-level contrasts (Figure 1). This procedure ensured that any overall statistically significant difference across the five sites would also be present at each site, at least at trend level. Statistical inferences were made using a minimum extent threshold of 50 voxels.

The total intracranial volume (TIV) for each image was estimated by first calculating the volume of gray matter, white matter and CSF separately at each voxel from the segmented images; the total volume for each type of tissue was then calculated by summing the respective voxel-level volumes; finally, TIV was obtained by adding the volume of all three tissue types. The effects of symptom severity, illness duration and anti-psychotic medication on the identified clusters were estimated using Pearson’s correlation between the values of GMV for the peak coordinate of each statistically significant cluster and each one of the clinical variables of interest. The raw psychotic symptom severity scores (acquired with either PANSS or SANS/SAPS) were first normalized to ensure comparability across sites. This normalisation was achieved using the following formula:

$$New\ score = \frac{Individual\ raw\ score - Minimum}{Maximum - Minimum}$$

where Minimum and Maximum refer to the lowest and highest score allowed for either PANSS or SAPS/SANS. The resulting disease severity scores were scaled between 0 and 1. Across all sites (except site 1, where all patients were AP-naïve), AP medication dose was estimated by calculating the chlorpromazine equivalent (mg/day) for each individual according to Gardner et al. (2010). Both chlorpromazine equivalent and duration of illness were log transformed. The statistical significance of Pearson’s correlation was assessed using a p -value < 0.05 with Bonferroni correction for multiple comparisons.

3 Results

3.1 Socio-demographic and clinical parameters

There were no significant differences between FEP and HC in gender, age and TIV, both when considering all sites together and within each single site. Patients reported comparable median duration of illness across sites (Table 1).

3.2.1 Decreased GMV in FEP compared to HC—Relative to HC, FEP showed a widespread pattern of decreased GMV in fronto-temporal, insular and occipital regions bilaterally (see Table 2 and Figure 2.A1). The most pronounced GMV decrease was found in the left gyrus rectus, located in the inferior frontal lobe (Figure 2.A2; the mean-plots for the remaining significant clusters are shown in the supplementary materials sFigure 1); negative correlations were found between GVM in this region and severity of both positive and negative symptoms. The right lingual gyrus also showed negative correlations with both positive and negative symptoms as well as with duration of illness. In addition, negative correlations were found between both the left inferior temporal gyrus and the left fusiform gyrus and positive symptoms (Table 3). No significant associations were detected between any brain region and anti-psychotic medication (Table 3). Scatter plots for the significant correlations are reported in the supplementary materials sFigure 2.

3.2.2 Increased GMV in FEP compared to HC—A significant increase in GMV in FEP relative to HC was found in the right superior temporal gyrus (Table 2 and Figure 2.B). The volume of this region was not significantly associated with severity of positive or negative symptoms, duration of illness or anti-psychotic medication (Table 3).

4 Discussion

Most previous studies on the neuroanatomical basis of FEP have used small samples recruited within a single site, and have yielded heterogeneous findings (Radua *et al.* 2012; Gao *et al.* 2017; Shah *et al.* 2017). The aim of this study was to use a multi-centre mega-analytic approach to identify neuroanatomical changes in FEP that are expressed consistently across several independent studies. As hypothesized, we found a widespread bilateral pattern of GMV decrease in fronto-temporal, insular and occipital regions. Some of these effects, particularly in the orbitofrontal and lingual gyri, were correlated with symptom severity and duration of illness. In addition, an increase in GMV was found in the right superior temporal lobe. Critically, all patients were experiencing their first episode of psychosis and one of the five samples was medication-naïve. In what follows, we discuss the brain structures that emerged from this study as well as their main role in the psychopathology of the early stages of psychosis.

Orbitofrontal cortex

A significant decrease in GMV was found in two sub-regions of the orbitofrontal cortex (OFC), namely the gyrus rectus (straight gyrus) and the orbital gyrus (Buchanan *et al.*, 2004; Nakamura *et al.*, 2007). Grey matter deficits in the OFC have been reported in established psychosis (e.g. Kim *et al.* 2017; Kong *et al.* 2015; Rimol *et al.* 2012; Xu *et al.* 2017) and, to a lesser extent, in FEP (e.g. Crespo-Facorro *et al.* 2000; Huang *et al.* 2015; Liao *et al.* 2015; Tordesillas-Gutierrez *et al.* 2015; Keymer-Gausset *et al.* 2018), consistent with the so-called “hypo-frontality” hypothesis of psychosis; although increases in this region have also been observed (Gao *et al.* 2017). The OFC has been implicated in multiple functions, including cognitive flexibility, reward learning and decision making (see Kringelbach 2005 and Schoenbaum *et al.* 2009 for a review), most of which are impaired in people with psychosis (Murray *et al.* 2008; Aas *et al.* 2014; Strauss *et al.* 2014; Premkumar *et al.* 2015). The gyrus

rectus (straight gyrus) was the region with the most pronounced decrease in GMV within the OFC and the whole brain. Consistent with our finding, this region has been reported to be decreased in FEP regardless of anti-psychotic medication status in a recent meta-analysis (Shah *et al.* 2017). This is also consistent with the lack of a statistically significant association between this region and anti-psychotic medication found in the present study. A decrease in GMV in the gyrus rectus was also found in the largest single-site VBM study of first-episode patients to date which included 93 FEP participants and 175 controls (Meisenzahl *et al.* 2008); although evidence for normal volume has also been reported (Roiz-Santiáñez *et al.* 2011; Takayanagi *et al.* 2011). As hypothesized, GMV in the gyrus rectus was inversely related to positive and negative symptoms – consistent with previous studies (Szendi *et al.* 2006; Sans-Sansa *et al.* 2013; Kim *et al.* 2017).

Insula

Despite inconsistencies across individual studies, most of the existing literature indicates deficits in the insular cortex of people with FEP, albeit with some inconsistencies in the exact location of the effect (Crespo-Facorro, Kim, Andreasen, O’Leary, Bockholt, *et al.*, 2000; Shah *et al.*, 2017; Gao *et al.*, 2018). In the present investigation it was the anterior part of the insula that showed reduced GMV. This region plays an important role in salience processing (Menon and Uddin, 2010), emotional appraisal and social cognition (Eckert *et al.* 2009), all of which are affected in psychosis (Wylie and Tregellas, 2010). Notably, grey matter deficits in the insula, as well as in the gyrus rectus and superior temporal gyrus, have also been found in individuals at ultra-high risk for psychosis who later transitioned to psychosis (Smieskova *et al.* 2010); this suggests reduced GMV in this region may represent a neuroanatomical signature of vulnerability to psychosis rather a marker of the actual illness. Furthermore, a GMV decrease in this region have been found to be expressed above and beyond ethnic variations in incidence and clinical expression (Gong *et al.* 2015).

Temporal cortex

Decreased GMV in temporal regions are amongst the most replicated findings in psychosis, including in FEP (Chan *et al.*, 2011; Radua *et al.*, 2012; Shah *et al.*, 2017). In this study, several temporal regions showed GMV deficits, namely the superior, middle and inferior gyri as well as the temporal portion of the fusiform gyrus bilaterally. GMV deficits in the left superior temporal gyrus are thought to play a central role in auditory verbal hallucinations in FEP patients (Modinos *et al.*, 2013; Benetti *et al.*, 2015), possibly due the role of this region in language perception and processing; it has been suggested that impairment to this region may lead to a misattribution of internal speech (Frith & Done 1988; Mechelli *et al.* 2007). The fusiform gyrus is also thought to play an important role in the psychopathology of psychosis, mainly due to its contribution to facial recognition (Haxby *et al.*, 2000; Haxby, Hoffman and Gobbini, 2002), which is impaired in psychosis (see Green *et al.* 2015 and Barkl *et al.* 2014 for a review) and is often seen as a proxy for the social cognition deficits characteristic of the illness (Green, Horan and Lee, 2015). Perhaps more challenging to interpret is the significant increase in GMV in right superior temporal gyrus. Nevertheless, increases in patients relative to controls across the brain, including the temporal cortex, have been reported before (Radewicz *et al.*, 2000; Kim *et al.*, 2003; Taylor *et al.*, 2005; Lee *et al.*, 2011), and are typically interpreted in terms of a “compensatory

mechanism” (Guo *et al.*, 2016) or a transient inflammation resulting from increased apoptotic activity during which apoptotic cells are removed (Berger *et al.* 2003; Adler *et al.* 2005).

Lingual gyrus

Evidence supporting structural abnormalities in the lingual gyrus in FEP has not been as consistent, with some studies reporting decreased (Ellison-Wright *et al.* 2008) and others increased (Gao *et al.* 2017) GMV. Such inconsistency may be explained by medication status, as shown by Shah *et al.* (2017), where GMV of the lingual gyrus was decreased in anti-psychotic naive FEP patients but increased in FEP patients under-going anti-psychotic treatment. However, in our study, which included both samples with and without exposure to anti-psychotics, there was a consistent GMV decrease in the lingual gyrus in the five sites, suggesting that a GMV decrease in this region may be present above and beyond medication status. Nevertheless, the lingual gyrus was significantly associated with anti-psychotic medication, therefore indicating that this region may be particularly prone to alterations when exposed to medication. The lingual gyrus is involved mainly in visual processing (Lee *et al.* 2000; Hahn *et al.* 2006) which has been shown to be impaired in psychosis (see Butler *et al.* 2008 and Silverstein & Keane 2011 for a review) and are also thought to underlie some of the cognitive impairments characteristic of the illness (Surti *et al.* 2011; Surti & Wexler, 2012; Contreras *et al.* 2018). The lingual gyrus also contributes to the evaluation of emotional faces (Fusar-Poli *et al.* 2009) which, together with the deficits found in the fusiform gyrus, may explain social cognition impairments in psychosis (Green, Horan and Lee, 2015).

Limitations

A first limitation of this study was that clinical data was acquired using different instruments (positive symptoms were assessed with either the PANSS or SAPS and negative symptoms with the PANSS or SANS). We overcame this limitation by normalizing individual scores within each scale as in previously studies (Gong *et al.* 2018). The resulting scores were highly correlated ($r=.87$) with automated methods to convert scores between these two widely used scales (van Erp *et al.* 2014). A further limitation is that there were differences in age, gender and clinical presentation across the five samples. However, we do not think this undermines the reliability of our findings, since our statistical analysis tested for common neuroanatomical abnormalities across the five sites rather than site-specific effects. Additionally, the MRI data was not harmonized across sites using dedicated approaches such as ComBat (Johnson, Li and Rabinovic, 2006), which could have improved the reliability of the results. The majority of VBM studies so far, including the present study, have used the DARTEL approach in-built in SPM to create study-specific templates. Although this is a well-established method, future studies could benefit from the use of recent alternative approaches, such as ANTs (<http://stnava.github.io/ANTs/>). A final limitation is that the five datasets differed with respect to anti-psychotic medication, with one sample being medication-naïve and the remaining four samples receiving various degrees of medication (Table 1). Critically, when we examined the impact of anti-psychotic medication on the findings, we found little evidence of statistically significant effects. This can be explained by

the fact that our findings were based on consistent neuroanatomical abnormalities across the five datasets, which included both medicated and non-medicated samples.

Conclusion

This study aimed to overcome the limitations of small and single-site studies by conducting a multi-centre mega-analysis of neuroanatomical abnormalities in FEP. To the best of our knowledge this is the largest VBM study in FEP to date. We found a widespread pattern of fronto-temporal, insular and occipital decreased GMV in FEP that were expressed consistently across five independent studies; overall, these decreases were not affected by anti-psychotic medication. This provides evidence for reliable neuroanatomical alternations in FEP, expressed above and beyond site-related differences in anti-psychotic medication, scanning parameters, and recruitment criteria. With the increasingly availability of larger datasets, future multi-centre mega-analyses could investigate the diagnostic specificity of these findings by integrating data collected from people with different psychiatric diagnoses (Ellison-Wright and Bullmore, 2010; Gong *et al.*, 2018).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

- Aas, M, Dazzan, P, Mondelli, V, Melle, I, Murray, RM, Pariante, CM. A Systematic Review of Cognitive Function in First-Episode Psychosis, Including a Discussion on Childhood Trauma, Stress, and Inflammation. *Frontiers in Psychiatry*. Vol. 4. Frontiers; 2014. 182
- Adler, CM, Levine, AD, DelBello, MP, Strakowski, SM. Changes in Gray Matter Volume in Patients with Bipolar Disorder. *Biological Psychiatry*. Vol. 58. Elsevier; 2005. 151–157.
- Andreasen, NC, Flaum, M, Arndt, S. The Comprehensive Assessment of Symptoms and History (CASH). *Archives of General Psychiatry*. Vol. 49. American Medical Association; 1992. 615
- APA. Diagnostic and Statistical Manual of Mental Disorders 4th Edition (DSM-IV-TR). Washington, DC: American Psychiatric Association; 2000.
- Ashburner, J. A fast diffeomorphic image registration algorithm. *NeuroImage*. Vol. 38. Academic Press; 2007. 95–113.
- Ashburner J, Friston KJ. Unified segmentation. *NeuroImage*. 2005; 26(3):839–851. DOI: 10.1016/j.neuroimage.2005.02.018 [PubMed: 15955494]
- Barkl, SJ, Lah, S, Harris, AWF, Williams, LM. Facial emotion identification in early-onset and first-episode psychosis: A systematic review with meta-analysis. *Schizophrenia Research*. Vol. 159. Elsevier; 2014. 62–69.
- Bebbington P, Nayani T. The psychosis screening questionnaire. *International Journal of Methods in Psychiatric Research*. 1995; 5:11–19.
- Benetti S, Pettersson-Yeo W, Allen P, Catani M, Williams S, Barsaglini A, Kambeitz-Ilankovic LM, McGuire P, Mechelli A. Auditory Verbal Hallucinations and Brain Dysconnectivity in the

- Perisylvian Language Network: A Multimodal Investigation. *Schizophrenia Bulletin*. 2015; 41(1):192–200. DOI: 10.1093/schbul/sbt172 [PubMed: 24361862]
- Berger GE, Wood S, McGorry PD. Incipient neurovulnerability and neuroprotection in early psychosis. *Psychopharmacology bulletin*. 2003; 37(2):79–101. Accessed: 6 September 2018
- Bora E, Fornito A, Radua J, Walterfang M, Seal M, Wood SJ, Yücel M, Velakoulis D, Pantelis C. Neuroanatomical abnormalities in schizophrenia: A multimodal voxelwise meta-analysis and meta-regression analysis *Schizophrenia Research*. Vol. 127. Elsevier; 2011. 46–57.
- Buchanan RW, Francis A, Arango C, Miller K, Lefkowitz DM, McMahon RP, Barta PE, Pearlson, GD. Morphometric Assessment of the Heteromodal Association Cortex in Schizophrenia *American Journal of Psychiatry*. Vol. 161. American Psychiatric Publishing; 2004. 322–331.
- Butler PD, Silverstein SM, Dakin SC. Visual Perception and Its Impairment in Schizophrenia *Biological Psychiatry*. Vol. 64. Elsevier; 2008. 40–47.
- Button KS, Ioannidis JPA, Mokrysz C, Nosek BA, Flint J, Robinson ESJ, Munafò MR. Power failure: why small sample size undermines the reliability of neuroscience *Nature Reviews Neuroscience*. Vol. 14. Nature Publishing Group; 2013. 365–376.
- Chan RCK, Di X, McAlonan GM, Gong Q. Brain anatomical abnormalities in high-risk individuals, first-episode, and chronic schizophrenia: an activation likelihood estimation meta-analysis of illness progression *Schizophrenia bulletin*. Vol. 37. Oxford University Press; 2011. 177–88.
- Chua SE, Cheung C, Cheung V, Tsang JTK, Chen EYH, Wong JCH, Cheung JPY, Yip L, Tai K-S, Suckling J, McAlonan GM. Cerebral grey, white matter and csf in never-medicated, first-episode schizophrenia *Schizophrenia research*. Vol. 89. Elsevier; 2007. 12–21.
- Contreras NA, Tan EJ, Lee SJ, Castle DJ, Rossell SL. Using visual processing training to enhance standard cognitive remediation outcomes in schizophrenia: A pilot study *Psychiatry Research*. Vol. 262. Elsevier; 2018. 494–499.
- Crespo-Facorro B, Kim J-J, Andreasen NC, O’Leary DS, Bockholt HJ, Magnotta V. Insular cortex abnormalities in schizophrenia: a structural magnetic resonance imaging study of first-episode patients *Schizophrenia research*. Vol. 46. Elsevier; 2000. 35–43.
- Crespo-Facorro B, Kim J-J, Andreasen NC, O’Leary DS, Magnotta V. Regional frontal abnormalities in schizophrenia: a quantitative gray matter volume and cortical surface size study *Biological Psychiatry*. Vol. 48. Elsevier; 2000. 110–119.
- Eckert MA, Menon V, Walczak A, Ahlstrom J, Denslow S, Horwitz A, Dubno JR. At the heart of the ventral attention system: The right anterior insula *Human Brain Mapping*. Vol. 30. Wiley-Blackwell; 2009. 2530–2541.
- Ellison-Wright I, Bullmore E. Anatomy of bipolar disorder and schizophrenia: A meta-analysis *Schizophrenia Research*. Vol. 117. Elsevier; 2010. 1–12.
- Ellison-Wright I, Glahn DC, Laird AR, Thelen SM, Bullmore E. The Anatomy of First-Episode and Chronic Schizophrenia: An Anatomical Likelihood Estimation Meta-Analysis *American Journal of Psychiatry*. Vol. 165. American Psychiatric Association; 2008. 1015–1023.
- van Erp TGM, , et al. Subcortical brain volume abnormalities in 2028 individuals with schizophrenia and 2540 healthy controls via the ENIGMA consortium *Molecular Psychiatry*. Vol. 21. Nature Publishing Group; 2016. 547–553.
- van Erp TGM, , et al. Cortical Brain Abnormalities in 4474 Individuals With Schizophrenia and 5098 Control Subjects via the Enhancing Neuro Imaging Genetics Through Meta Analysis (ENIGMA) Consortium *Biological Psychiatry*. Vol. 84. Elsevier; 2018. 644–654.
- van Erp TGM, Preda A, Nguyen D, Faziola L, Turner J, Bustillo J, Belger A, Lim KO, McEwen S, Voyvodic J, Mathalon DH, , et al. Converting positive and negative symptom scores between PANSS and SAPS/SANSS *Schizophrenia Research*. Vol. 152. Elsevier; 2014. 289–294.
- First MB, Gibbon M, Spitzer RL, W, J. Structured Clinical Interview for DSM-IV Axis II Personality Disorders. American Psychiatric Press; Washington: 1997.
- Di Forti M, Morgan C, Dazzan P, Pariante C, Mondelli V, Marques TR, Handley R, Luzi S, Russo M, Paparelli A, Butt A, , et al. High-potency cannabis and the risk of psychosis *British Journal of Psychiatry*. Vol. 195. Cambridge University Press; 2009. 488–491.
- Fusar-Poli P, Placentino A, Carletti F, Landi P, Allen P, Surguladze S, Benedetti F, Abbamonte M, Gasparotti R, Barale F, Perez J, , et al. Functional atlas of emotional faces processing: a voxel-

- based meta-analysis of 105 functional magnetic resonance imaging studies *Journal of psychiatry & neuroscience : JPN*. Vol. 34. Canadian Medical Association; 2009. 418–32. [Accessed: 5 September 2018]
- Fusar-Poli, P, Radua, J, McGuire, P, Borgwardt, S. Neuroanatomical Maps of Psychosis Onset: Voxel-wise Meta-Analysis of Antipsychotic-Naive VBM Studies *Schizophrenia Bulletin*. Vol. 38. Oxford University Press; 2012. 1297–1307.
- Gao X, Zhang W, Yao L, Xiao Y, Liu L, Liu J, Li S, Tao B, Shah C, Gong Q, Sweeney JA, et al. Association between structural and functional brain alterations in drug-free patients with schizophrenia: a multimodal meta-analysis. *J Psychiatry Neurosci*. 2018; 43(2):131–142. DOI: 10.1503/jpn.160219 [PubMed: 29481320]
- Gardner DM, Murphy AL, O'Donnell H, Centorrino F, Baldessarini RJ. International Consensus Study of Antipsychotic Dosing. *American Journal of Psychiatry*. 2010; 167(6):686–693. DOI: 10.1176/appi.ajp.2009.09060802
- Glahn, DC, Laird, AR, Ellison-Wright, I, Thelen, SM, Robinson, JL, Lancaster, JL, Bullmore, E, Fox, PT. Meta-Analysis of Gray Matter Anomalies in Schizophrenia: Application of Anatomic Likelihood Estimation and Network Analysis *Biological Psychiatry*. Vol. 64. Elsevier; 2008. 774–781.
- Gong, Q, Dazzan, P, Scarpazza, C, Kasai, K, Hu, X, Marques, TR, Iwashiro, N, Huang, X, Murray, RM, Koike, S, David, AS, et al. A Neuroanatomical Signature for Schizophrenia Across Different Ethnic Groups *Schizophrenia bulletin*. Vol. 41. Oxford University Press; 2015. 1266–75.
- Gong, Q, Scarpazza, C, Dai, J, He, M, Xu, X, Shi, Y, Zhou, B, Vieira, S, McCrory, E, Ai, Y, Yang, C, et al. A transdiagnostic neuroanatomical signature of psychiatric illness *Neuropsychopharmacology*. Nature Publishing Group; 2018. 1
- Green, MF, Horan, WP, Lee, J. Social cognition in schizophrenia *Nature Reviews Neuroscience*. Vol. 16. Nature Publishing Group; 2015. 620–631.
- Guo, S, Palaniyappan, L, Liddle, PF, Feng, J. Dynamic cerebral reorganization in the pathophysiology of schizophrenia: a MRI-derived cortical thickness study *Psychological Medicine*. Vol. 46. Cambridge University Press; 2016. 2201–2214.
- Gupta, CN, et al. Patterns of Gray Matter Abnormalities in Schizophrenia Based on an International Mega-analysis *Schizophrenia Bulletin*. Vol. 41. Oxford University Press; 2015. 1133–1142.
- Hahn B, Ross TJ, Stein EA. Neuroanatomical dissociation between bottom-up and top-down processes of visuospatial selective attention. *NeuroImage*. 2006; 32(2):842–853. DOI: 10.1016/j.neuroimage.2006.04.177 [PubMed: 16757180]
- Haxby, JV; Hoffman, EA; Gobbini, MI. [Accessed: 5 September 2018] Human Neural Systems for Face Recognition and Social Communication. *Biol Psychiatry*. 2002. Available at: https://ac.els-cdn.com/S0006322301013300/1-s2.0-S0006322301013300-main.pdf?_tid=832ee091-e784-497a-bbad-0d006bc6ec73&acdnat=1536165522_f68360f7c271aaf3efe32f5f4cb3e41
- Haxby, James V; Hoffman, Elizabeth A; Gobbini, M Ida; Haxby, JV; Hoffman, EA; Gobbini, MI. The distributed human neural system for face perception. *Trends in Cognitive Sciences*. 2000; 4(6):223–233. Accessed: 5 September 2018 [PubMed: 10827445]
- Huang, P, Xi, Y, Lu, Z-L, Chen, Y, Li, X, Li, W, Zhu, X, Cui, L-B, Tan, Q, Liu, W, Li, C, et al. Decreased bilateral thalamic gray matter volume in first-episode schizophrenia with prominent hallucinatory symptoms: A volumetric MRI study *Scientific Reports*. Vol. 5. Nature Publishing Group; 2015. 14505
- Jayakumar, PN, Venkatasubramanian, G, Gangadhar, BN, Janakiramaiah, N, Keshavan, MS. Optimized voxel-based morphometry of gray matter volume in first-episode, antipsychotic-naïve schizophrenia *Progress in Neuro-Psychopharmacology and Biological Psychiatry*. Vol. 29. Elsevier; 2005. 587–591.
- Johnson WE, Li C, Rabinovic A. Adjusting batch effects in microarray expression data using empirical Bayes methods. *Biostatistics*. 2006; 8(1):118–127. [PubMed: 16632515]
- Keymer-Gausset, A, Alonso-Solís, A, Corripio, I, Sauras-Quetcuti, RB, Pomarol-Clotet, E, Canales-Rodriguez, EJ, Grasa-Bello, E, Álvarez, E, Portella, MJ. Gray and white matter changes and their relation to illness trajectory in first episode psychosis *European Neuropsychopharmacology*. Vol. 28. Elsevier; 2018. 392–400.

- Kim, G-W, Kim, Y-H, Jeong, G-W. Whole brain volume changes and its correlation with clinical symptom severity in patients with schizophrenia: A DARTEL-based VBM study *PLOS ONE*. Hashimoto, K, editor. Vol. 12. Public Library of Science; 2017. e0177251
- Kim, J-J, Crespo-Facorro, B, Andreasen, NC, O'Leary, DS, Magnotta, V, Nopoulos, P. Morphology of the lateral superior temporal gyrus in neuroleptic naïve patients with schizophrenia: relationship to symptoms *Schizophrenia Research*. Vol. 60. Elsevier; 2003. 173–181.
- Kong, L, Herold, CJ, Zöllner, F, Salat, DH, Lässer, MM, Schmid, LA, Fellhauer, I, Thomann, PA, Essig, M, Schad, LR, Erickson, KI, et al. Comparison of grey matter volume and thickness for analysing cortical changes in chronic schizophrenia: A matter of surface area, grey/white matter intensity contrast, and curvature *Psychiatry Research: Neuroimaging*. Vol. 231. Elsevier; 2015. 176–183.
- Korver, N, Quee, PJ, Boos, HBM, Simons, CJP, de Haan, L. Genetic Risk and Outcome of Psychosis (GROUP), a multi site longitudinal cohort study focused on gene-environment interaction: objectives, sample characteristics, recruitment and assessment methods *International Journal of Methods in Psychiatric Research*. Vol. 21. Wiley-Blackwell; 2012. 205–221.
- Kringelbach ML. The human orbitofrontal cortex: linking reward to hedonic experience. *Nature Reviews Neuroscience*. 2005; 6(9):691–702. DOI: 10.1038/nrn1747 [PubMed: 16136173]
- Lee, HW, Hong, SB, Seo, DW, Tae, WS, Hong, SC. Mapping of functional organization in human visual cortex: electrical cortical stimulation *Neurology*. Vol. 54. Wolters Kluwer Health, Inc. on behalf of the American Academy of Neurology; 2000. 849–54.
- Lee, JS, Park, H-J, Chun, JW, Seok, J-H, Park, I-H, Park, B, Kim, J-J. Neuroanatomical correlates of trait anhedonia in patients with schizophrenia: A voxel-based morphometric study *Neuroscience Letters*. Vol. 489. Elsevier; 2011. 110–114.
- Liao, J, Yan, H, Liu, Q, Yan, J, Zhang, L, Jiang, S, Zhang, X, Dong, Z, Yang, W, Cai, L, Guo, H, et al. Reduced paralimbic system gray matter volume in schizophrenia: Correlations with clinical variables, symptomatology and cognitive function *Journal of Psychiatric Research*. Vol. 65. Pergamon; 2015. 80–86.
- Mechelli A, Price CJ, Friston KJ, Ashburner J. Voxel-Based Morphometry of the Human Brain: Methods and Applications. *Current Medical Imaging Reviews*. 2005; doi: 10.2174/1573405054038726
- Meisenzahl, EM, Koutsouleris, N, Bottlender, R, Scheuerecker, J, Jäger, M, Teipel, SJ, Holzinger, S, Frodl, T, Preuss, U, Schmitt, G, Burgermeister, B, et al. Structural brain alterations at different stages of schizophrenia: A voxel-based morphometric study *Schizophrenia Research*. Vol. 104. Elsevier; 2008. 44–60.
- Menon, V, Uddin, LQ. Saliency, switching, attention and control: a network model of insula function *Brain structure & function*. Vol. 214. NIH Public Access; 2010. 655–67.
- Modinos, G, Costafreda, SG, van Tol, M-J, McGuire, PK, Aleman, A, Allen, P. Neuroanatomy of auditory verbal hallucinations in schizophrenia: A quantitative meta-analysis of voxel-based morphometry studies *Cortex*. Vol. 49. Elsevier; 2013. 1046–1055.
- Murray, GK, Cheng, F, Clark, L, Barnett, JH, Blackwell, AD, Fletcher, PC, Robbins, TW, Bullmore, ET, Jones, PB. Reinforcement and Reversal Learning in First-Episode Psychosis *Schizophrenia Bulletin*. Vol. 34. Oxford University Press; 2008. 848–855.
- Nakamura, M, Nestor, PG, Levitt, JJ, Cohen, AS, Kawashima, T, Shenton, ME, McCarley, RW. Orbitofrontal volume deficit in schizophrenia and thought disorder *Brain*. Vol. 131. Oxford University Press; 2007. 180–195.
- Olabi, B, Ellison-Wright, I, McIntosh, AM, Wood, SJ, Bullmore, E, Lawrie, SM. Are There Progressive Brain Changes in Schizophrenia? A Meta-Analysis of Structural Magnetic Resonance Imaging Studies *Biological Psychiatry*. Vol. 70. Elsevier; 2011. 88–96.
- Pelayo-Terán, JM, Pérez-Iglesias, R, Ramírez-Bonilla, M, González-Blanch, C, Martínez-García, O, Pardo-García, G, Rodríguez-Sánchez, JM, Roiz-Santiañez, R, Tordesillas-Gutiérrez, D, Mata, I, Vázquez-Barquero, JL, et al. Epidemiological factors associated with treated incidence of first-episode non-affective psychosis in Cantabria: insights from the Clinical Programme on Early Phases of Psychosis *Early Intervention in Psychiatry*. Vol. 2. Wiley/Blackwell; 2008. 178–187. (10.1111)

- Premkumar, P, Fannon, D, Sapara, A, Peters, ER, Anilkumar, AP, Simmons, A, Kuipers, E, Kumari, V. Orbitofrontal cortex, emotional decision-making and response to cognitive behavioural therapy for psychosis *Psychiatry Research: Neuroimaging*. Vol. 231. Elsevier; 2015. 298–307.
- Radewicz, K, Garey, LJ, Gentleman, SM, Reynolds, R. Increase in HLA-DR Immunoreactive Microglia in Frontal and Temporal Cortex of Chronic Schizophrenics *Journal of Neuropathology & Experimental Neurology*. Vol. 59. Oxford University Press; 2000. 137–150.
- Radua, J, Borgwardt, S, Crescini, A, Mataix-Cols, D, Meyer-Lindenberg, A, McGuire, PK, Fusar-Poli, P. Multimodal meta-analysis of structural and functional brain changes in first episode psychosis and the effects of antipsychotic medication *Neuroscience & Biobehavioral Reviews*. Vol. 36. Pergamon; 2012. 2325–2333.
- Ren, W, Lui, S, Deng, W, Li, F, Li, M, Huang, X, Wang, Y, Li, T, Sweeney, JA, Gong, Q. Anatomical and Functional Brain Abnormalities in Drug-Naive First-Episode Schizophrenia *American Journal of Psychiatry*. Vol. 170. American Psychiatric Association; Arlington, VA: 2013. 1308–1316.
- Rimol, LM, Nesvåg, R, Hagler, DJ, Bergmann, Ø, Fennema-Notestine, C, Hartberg, CB, Haukvik, UK, Lange, E, Pung, CJ, Server, A, Melle, I, et al. Cortical Volume, Surface Area, and Thickness in Schizophrenia and Bipolar Disorder *Biological Psychiatry*. Vol. 71. Elsevier; 2012. 552–560.
- Roiz-Santiáñez, R, Pérez-Iglesias, R, Ortiz-García de la Foz, V, Tordesillas-Gutiérrez, D, Mata, I, Marco de Lucas, E, Pazos, A, Tabarés-Seisdedos, R, Vázquez-Barquero, JL, Crespo-Facorro, B. Straight gyrus morphology in first-episode schizophrenia-spectrum patients *Progress in Neuro-Psychopharmacology and Biological Psychiatry*. Vol. 35. Elsevier; 2011. 84–90.
- Rozycki M, Satterthwaite TD, Koutsouleris N, Erus G, Doshi J, Wolf DH, Fan Y, Gur RE, Gur RC, Meisenzahl EM, Zhuo C, et al. Multisite Machine Learning Analysis Provides a Robust Structural Imaging Signature of Schizophrenia Detectable Across Diverse Patient Populations and Within Individuals. *Schizophrenia Bulletin*. 2018; 44(5):1035–1044. DOI: 10.1093/schbul/sbx137 [PubMed: 29186619]
- Salgado-Pineda, P, Baeza, I, Pérez-Gómez, M, Vendrell, P, Junqué, C, Bargalló, N, Bernardo, M. Sustained attention impairment correlates to gray matter decreases in first episode neuroleptic-naive schizophrenic patients *NeuroImage*. Vol. 19. Academic Press; 2003. 365–375.
- Sans-Sansa, B, McKenna, PJ, Canales-Rodríguez, EJ, Ortiz-Gil, J, López-Araquistain, L, Sarró, S, Dueñas, RM, Blanch, J, Salvador, R, Pomarol-Clotet, E. Association of formal thought disorder in schizophrenia with structural brain abnormalities in language-related cortical regions *Schizophrenia Research*. Vol. 146. Elsevier; 2013. 308–313.
- Schoenbaum G, Roesch MR, Stalnaker TA, Takahashi YK. A new perspective on the role of the orbitofrontal cortex in adaptive behaviour. *Nature Reviews Neuroscience*. 2009; 10(12):885–892. DOI: 10.1038/nrn2753 [PubMed: 19904278]
- Shah, C, Zhang, W, Xiao, Y, Yao, L, Zhao, Y, Gao, X, Liu, L, Liu, J, Li, S, Tao, B, Yan, Z, et al. Common pattern of gray-matter abnormalities in drug-naive and medicated first-episode schizophrenia: a multimodal meta-analysis *Psychological Medicine*. Vol. 47. Cambridge University Press; 2017. 401–413.
- Silverstein, SM, Keane, BP. Perceptual Organization Impairment in Schizophrenia and Associated Brain Mechanisms: Review of Research from 2005 to 2010 *Schizophrenia Bulletin*. Vol. 37. Oxford University Press; 2011. 690–699.
- Smieskova, R, Fusar-Poli, P, Allen, P, Bendfeldt, K, Stieglitz, RD, Drewe, J, Radue, EW, McGuire, PK, Riecher-Rössler, A, Borgwardt, SJ. Neuroimaging predictors of transition to psychosis—A systematic review and meta-analysis *Neuroscience & Biobehavioral Reviews*. Vol. 34. Pergamon; 2010. 1207–1222.
- Strauss, GP, Waltz, JA, Gold, JM. A Review of Reward Processing and Motivational Impairment in Schizophrenia *Schizophrenia Bulletin*. Vol. 40. Oxford University Press; 2014. S107–S116.
- Surti TS, Corbera S, Bell MD, Wexler BE. Successful computer-based visual training specifically predicts visual memory enhancement over verbal memory improvement in schizophrenia. *Schizophrenia Research*. 2011; 132(2–3):131–134. DOI: 10.1016/j.schres.2011.06.031 [PubMed: 21795025]
- Surti TS, Wexler BE. A pilot and feasibility study of computer-based training for visual processing deficits in schizophrenia. *Schizophrenia Research*. 2012; 142(1–3):248–249. DOI: 10.1016/j.schres.2012.09.013 [PubMed: 23043873]

- Szendi, I, Kiss, M, Racsmány, M, Boda, K, Cimner, C, Vörös, E, Kovács, ZA, Szekeres, G, Galsi, G, Pléh, C, Csernay, L. , et al. Correlations between clinical symptoms, working memory functions and structural brain abnormalities in men with schizophrenia *Psychiatry Research: Neuroimaging*. Vol. 147. Elsevier; 2006. 47–55.
- Takayanagi, Y, Takahashi, T, Orikabe, L, Mozue, Y, Kawasaki, Y, Nakamura, K, Sato, Y, Itokawa, M, Yamasue, H, Kasai, K, Kurachi, M. , et al. Classification of first-episode schizophrenia patients and healthy subjects by automated MRI measures of regional brain volume and cortical thickness *PLoS ONE*. Harrison, BJ, editor. Vol. 6. Public Library of Science; 2011. 1–10.
- Tang, J, Liao, Y, Zhou, B, Tan, C, Liu, W, Wang, D, Liu, T, Hao, W, Tan, L, Chen, X. Decrease in temporal gyrus gray matter volume in first-episode, early onset schizophrenia: an MRI study *PLoS one*. Bruce, A, editor. Vol. 7. Public Library of Science; 2012. e40247
- Taylor, JL, Blanton, RE, Levitt, JG, Caplan, R, Nobel, D, Toga, AW. Superior temporal gyrus differences in childhood-onset schizophrenia *Schizophrenia Research*. Vol. 73. Elsevier; 2005. 235–241.
- Tordesillas-Gutierrez, D, Koutsouleris, N, Roiz-Santiañez, R, Meisenzahl, E, Ayasa-Arriola, R, Marco de Lucas, E, Soriano-Mas, C, Suarez-Pinilla, P, Crespo-Facorro, B, de Lucas, EM, Soriano-Mas, C. , et al. Grey matter volume differences in non-affective psychosis and the effects of age of onset on grey matter volumes: A voxelwise study *Schizophrenia research*. Vol. 164. Elsevier; 2015. 74–82.
- Venkatasubramanian, G. Neuroanatomical correlates of psychopathology in antipsychotic-naïve schizophrenia *Indian journal of psychiatry*. Vol. 52. Wolters Kluwer -- Medknow Publications; 2010. 28–36.
- Vita, A, De Peri, L, Deste, G, Barlati, S, Sacchetti, E. The Effect of Antipsychotic Treatment on Cortical Gray Matter Changes in Schizophrenia: Does the Class Matter? A Meta-analysis and Meta-regression of Longitudinal Magnetic Resonance Imaging Studies *Biological Psychiatry*. Vol. 78. Elsevier; 2015. 403–412.
- Vita, A, De Peri, L, Deste, G, Sacchetti, E. Progressive loss of cortical gray matter in schizophrenia: a meta-analysis and meta-regression of longitudinal MRI studies *Translational Psychiatry*. Vol. 2. Nature Publishing Group; 2012. e190
- WHO. International statistical classification of diseases and related health problems. World Health Organization; 2004.
- Wylie, KP, Tregellas, JR. The role of the insula in schizophrenia *Schizophrenia Research*. Vol. 123. Elsevier; 2010. 93–104.
- Xu, Y, Qin, W, Zhuo, C, Xu, L, Zhu, J, Liu, X, Yu, C. Selective functional disconnection of the orbitofrontal subregions in schizophrenia *Psychological Medicine*. Vol. 47. Cambridge University Press; 2017. 1637–1646.
- Yassa M, Stark C. A quantitative evaluation of cross-participant registration techniques for MRI studies of the medial temporal lobe. *NeuroImage*. 2009; 44(2):319–327. DOI: 10.1016/j.neuroimage.2008.09.016 [PubMed: 18929669]

Figure 1.

Inclusive masking procedure used to identify neuroanatomical abnormalities in FEP relative to HC consistent across all five sites. Left: an overall contrast with all FEP against all HC ($p < 0.05$ FWE corrected) was combined with five site-level contrasts ($p < 0.05$ uncorrected); this allowed us to identify only the voxels that survived both types of contrasts (intersection of all contrasts in black).

Figure 2.

A1) Regions showing statistically significant decreases in FEP relative to HC across the whole brain. A2) Location of the gyrus rectus (straight gyrus) where the most pronounced GMV decrease was found and mean and standard deviation of the GMV in this region for each site. B) Location of the right superior temporal gyrus (the only region showing statistically significant GMV increase in FEP relative to HC) and mean and standard deviation of the GMV in this region for each site.