Psychiatry Research: Neuroimaging 224 (2014) 184–191

Contents lists available at ScienceDirect

Psychiatry Research: Neuroimaging

journal homepage: www.elsevier.com/locate/psychresns

Distinct structural neural patterns of trait physical and social anhedonia: Evidence from cortical thickness, subcortical volumes and inter-regional correlations

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ARTICLE INFO

Article history:
Received 11 March 2014
Received in revised form
11 August 2014
Accepted 11 September 2014
Available online 19 September 2014

Keywords:
Anhedonia
Pallidum
Social interaction
Superior frontal gyrus
Inferior parietal gyrus

ABSTRACT

Anhedonia is an enduring trait accounting for the reduced capacity to experience pleasure. Few studies have investigated the brain structural features associated with trait anhedonia. In this study, the relationships between cortical thickness, volume of subcortical structures and scores on the Chapman physical and social anhedonia scales were examined in a non-clinical sample ($n=72$, 35 males). FreeSurfer was used to examine the cortical thickness and the volume of six identified subcortical structures related to trait anhedonia. We found that the cortical thickness of the superior frontal gyrus and the volume of the pallidum in the left hemisphere were correlated with anhedonia scores in both physical and social aspects. Specifically, positive correlations were found between levels of social anhedonia and the thickness of the postcentral and the inferior parietal gyri. Cortico-subcortical inter-correlations between these clusters were also observed. Our findings revealed distinct correlation patterns of neural substrates with trait physical and social anhedonia in a non-clinical sample. These findings contribute to the understanding of the pathologies underlying the anhedonia phenotype in schizophrenia and other psychiatric disorders.

1. Introduction

Anhedonia refers to a diminished capacity to experience pleasure. As a core feature in the dysfunction of reward processing, it has been proposed to be an important trait marker of schizophrenia and major depressive disorder (Meehl, 1990; Leboyer et al., 1998). Anhedonia can be broadly separated into physical and social aspects. Physical anhedonia is defined as a diminished hedonic capacity related to physical sensation induced by food, context, smell and sex; while social anhedonia is defined as the corresponding reduction in pleasure experience in social interactions (Chapman et al., 1976).

Recent functional magnetic resonance imaging (fMRI) studies have revealed a possible functional neural network underlying reward processing in relation to anhedonia (see review by Liu et al. (2011)). The nucleus accumbens (NAc), the caudate nucleus, the putamen, the ventral pallidum, the ventral medial prefrontal cortex and the orbitofrontal cortex have been proposed as key anatomical structures in this network (Liu et al., 2011; Pecina et al., 2006). In patients with schizophrenia, brain activity reductions in these regions have been found to be associated with trait physical anhedonia (Harvey et al., 2010; Lee et al., 2012). Meanwhile, abnormalities of brain structures including the prefrontal cortex, the thalamus, the amygdala and the basal ganglia including the ventral pallidum have been documented in patients with schizophrenia and major depressive disorder (Rigucci et al., 2010; Shepherd et al., 2012). Moreover, these regional brain morphological alterations have been found to be associated with the severity of negative symptoms attributed to anhedonia in patients with schizophrenia (Ballmaier et al., 2008; Yoshihara et al., 2008). Cortical thickness is a crucial element of cortical grey matter

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http://dx.doi.org/10.1016/j.pscychresns.2014.09.005
0925-4927/

morphology, which has been hypothesized to reflect dendritic branching/pruning within grey matter (Huttenlocher, 1990). Recent cortical-surface based studies also reported that patients with schizophrenia (Schultz et al., 2010; van Haren et al., 2011; Oertel-Knochel et al., 2013; Tully et al., 2014) and major depressive disorder (Tu et al., 2012) had thinner cortices in the temporal lobe and frontal lobe when compared with healthy individuals. Taken together, these neuroimaging findings suggest a cortico-subcortical neurobiological basis to study trait anhedonia.

As an enduring trait, anhedonia can be observed not only in patients with schizophrenia and major depressive disorder across different stages of the illness (Horan et al., 2005; Shankman et al., 2010), but also in the general population (Collins et al., 2005; Gooding et al., 2005; Harvey et al., 2007; Chan et al., 2012). Since clinical samples may be confounded by the heterogeneity of the disorder, duration of illness, and the effect of medication exposure, investigating anatomical alterations in a non-clinical sample may be able to minimize these confounds and lead to a better understanding of the neural mechanisms underlying the development of the disorder. It also allows us to examine the biological basis of trait anhedonia in a broader context. Similar to findings in patients with schizophrenia, brain activity reductions have been found to be related to trait anhedonia severity in reward processing associated network in non-clinical samples (Harvey et al., 2010; Keller et al., 2013). In addition, individuals with higher levels of anhedonia exhibit certain impairments in social cognition, which overlap with deficits found in patients with schizophrenia (Wang et al., 2013; Xie et al., 2014). They also showed smaller anterior caudate and NAc volumes (Harvey et al., 2007; Wacker et al., 2009) relative to those with lower scores. However, at the cortical level, little attention has been paid to the relationship between cortical thickness and trait anhedonia in non-clinical samples.

Moreover, existing evidence in anhedonia has largely focused on the physical domains (Harvey et al., 2010; Lee et al., 2012) rather than the social aspect. However, some studies have suggested that social anhedonia could potentially serve as a predictor of later development of schizophrenia spectrum disorders. For example, two prospective longitudinal studies have shown that individuals with higher social anhedonia scores on initial assessments had a higher chance of developing schizophrenia spectrum disorders 5 (15.6% in the high-score group and 0% in the low-score group) and 10 years later (24% in the high-score group and 1% in the low-score group) (Kwapil, 1998; Gooding et al., 2005). Furthermore, recent studies have also shown that individuals experiencing less pleasure in social interactions have hedonic deficits in social affect (Xie et al., 2014), greater negative-symptom-like characteristics and worse social functioning (Blanchard et al., 2011). Therefore, investigations of the neural correlates of trait anhedonia, especially the social aspect, may provide important information that could be used in the early identification and prevention of psychosis.

In this study, we examined the correlations between cortical thickness and the level of trait physical and social anhedonia in a non-clinical sample. We also examined the volume of subcortical regions related to anhedonia, including the caudate, the thalamus, the NAc, the putamen, the amygdala and the pallidum. In an attempt to identify possible interconnecting brain structural network related to trait anhedonia, we further explored the structural covariance between identified significant cortical clusters and the volumes of these anhedonia-related hot spots in the subcortical regions. We hypothesized that a higher level of anhedonia would correlate with thinner cortices, primarily in the frontal regions and smaller volumes in the subcortical regions. Since social anhedonia specifically affects the experience of pleasure in social interactions, we predicted a unique correlation pattern between social anhedonia scores and cortical thickness in brain regions that are involved in emotional response or social cognition. We also hypothesized a structural inter-correlation among these cortico-subcortical brain regions, together forming a possible neural circuit for trait anhedonia.

2. Methods

2.1. Participants

Seventy-two first-year college students (35 males and 37 females) between 17 and 21 years old (mean age=19.3 years, S.D.=0.9 years) were recruited from a medical university in China. All participants were right-handed as assessed by the Annett Handedness Scale (Annett, 1970). Exclusion criteria for participants included any psychiatric disorder, current or history of drug abuse, any neurological pathology, or those with a Beck Depression Inventory score (BDI, Beck et al., 1961) greater than 18. The BDI scores of the included participants ranged from 0 to 15 (mean=4.03, S.D.=4.48). Their IQs were estimated using the common sense, arithmetic, similarity and digit span subtests of the Chinese version Wechsler Adult Intelligence Scale-Revised (WAIS-R) (Gong and Dai, 1984), ranging from 88 to 139 (mean=117.11, S.D.=10.32). This study was approved by the Ethics Committee of the Institute of Psychology, Chinese Academy of Sciences. Written informed consent was obtained from each participant prior to testing.

2.2. Trait anhedonia measures

Participants were asked to complete a set of self-report questionnaires, consisting of the Chinese version of the revised Physical Anhedonia Scale (CPAS) and the revised Social Anhedonia Scale (CSAS), which have been validated in a previous study (Chan et al., 2012). The CPAS is a 61-item questionnaire assessing the lowered ability to experience pleasure related to physical sensation (e.g., "I have often enjoyed the feel of silk, velvet, or fur"; "I don't know why some people are so interested in music") (Chapman and Chapman, 1978), whereas the CSAS is a 40-item questionnaire assessing the lowered ability to experience pleasure induced by social interactions (e.g., "Just being with friends can make me feel really good"; "Making new friends isn't worth the energy it takes") (Eckblad et al., 1982). For each item in the CPAS and the CSAS, participants were asked to report their experience with a "Yes" or "No" answer. The total CPAS score and the total CSAS score were calculated separately for each participant. A higher total score indicates a higher level of anhedonia. In our sample, the total CPAS scores ranged from 0 to 40 (mean=11.47, S.D.=9.63), and the total CSAS scores ranged from 0 to 21 (mean=7.94, S.D.=5.58). The scores were similar to those reported in a previous study with a larger Chinese sample (Chan et al., 2012). The internal consistency coefficient was 0.92 for the CPAS and 0.84 for the CSAS.

2.3. Image acquisition and preprocessing

Structural images from all participants were acquired on a 3-Tesla scanner (Verio, Siemens). The scanning parameters of the T1-weighted three-dimensional magnetization-prepared rapid gradient-echo (3D MPRAGE) sequences were as follows: slice thickness=1 mm, TE=2.34 ms, TR=2530 ms, flip angle=7°, matrix size=256 × 256; 176 slices in sagittal plane, field of view (FOV)=256 mm, voxel size=1 × 1 × 1 mm^3. Images were inspected by experienced radiologists to exclude any individuals with brain structural abnormalities.

For cortical reconstruction of the whole brain, the FreeSurfer imaging analysis suite (v5.1.0, http://surfer.nmr.mgh.harvard.edu/) was used (Dale et al., 1999; Fischl and Dale, 2000). With this software, the T1-weighted images were registered to the Talairach space of each participant's brain with the skulls stripped. Images were then segmented into white matter/grey matter (WM/GM) tissue based on local and neighbouring intensities. The cortical surface of each hemisphere was inflated to an average spherical surface to locate both the pial surface and the WM/GM boundary. Preprocessed images were visually inspected before including into subsequent statistical analyses. Any topological defects were excluded from the subsequent analyses. In this study, none of participants were excluded at the preprocessing stage. Cortical thickness was measured based on the shortest distance between the pial surface and the GM/WM boundary at each point across the cortical mantle. The regional thickness value at each vertex for each participant was mapped to the surface of an average spherical surface (Fischl et al., 1999). In addition, for each participant, intracranial volume (ICV), and volumes of six subcortical structures (i.e. the putamen, the caudate, the amygdala, the thalamus, the nucleus accumbens and the pallidum) of each hemisphere were extracted using automated parcellation in FreeSurfer (Fischl et al., 2004).

2.4. Statistical analysis

2.4.1. Covariates of no interest

In this study, age, gender, IQ estimates and BDI scores were defined as covariates of no interest in the subsequent analyses. To minimize the effect of continuing grey matter maturation in the frontal lobe during adolescence and