Psychiatry Research: Neuroimaging 231 (2015) 333–340

Contents lists available at ScienceDirect

Psychiatry Research: Neuroimaging

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

Frontal and striatal alterations associated with psychopathic traits in adolescents

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ARTICLE INFO

Article history:
Received 7 February 2014
Received in revised form
15 May 2014
Accepted 16 January 2015
Available online 24 January 2015

Keywords:
Developmental
MRI
Tensor-based morphometry
Putamen

ABSTRACT

Neuroimaging research has demonstrated a range of structural deficits in adults with psychopathy, but little is known about structural correlates of psychopathic tendencies in adolescents. Here we examined structural magnetic resonance imaging (sMRI) data obtained from 14-year-old adolescents ($n = 108$) using tensor-based morphometry (TBM) to isolate global and localized differences in brain tissue volumes associated with psychopathic traits in this otherwise healthy developmental population. We found that greater levels of psychopathic traits were correlated with increased brain tissue volumes in the left putamen, left ansa peduncularis, right superiomedial prefrontal cortex, left inferior frontal cortex, right orbitofrontal cortex, and right medial temporal regions and reduced brain tissues volumes in the right middle frontal cortex, left superior parietal lobule, and left inferior parietal lobule. Post hoc analyses of parcellated regional volumes also showed putamen enlargements to correlate with increased psychopathic traits. Consistent with earlier studies, findings suggest poor decision-making and emotional dysregulation associated with psychopathy may be due, in part, to structural anomalies in frontal and temporal regions whereas striatal structural variations may contribute to sensation-seeking and reward-driven behavior in psychopathic individuals. Future studies will help clarify how disturbances in brain maturational processes might lead to the developmental trajectory from psychopathic tendencies in adolescents to adult psychopathy.

1. Introduction

Psychopathy is a clinical condition defined by a combination of persistent antisocial behavior, marked sensation-seeking, impulsivity, shallow emotion, blunted empathy, and punishment insensitivity that emerges early in life (Hare, 2003). Although a diagnostic level of psychopathy is present in only 1–2% of the general population, it is widely present on a spectrum in otherwise healthy populations. Research on the neural bases of psychopathy has focused largely on the profound emotional deficits and antisocial behavior observed in psychopathic adults, emphasizing the possible contributions of a disturbed frontolimbic circuitry (Gao et al., 2009; Yang and Raine, 2009). To date, findings from several structural imaging studies have supported this argument by showing frontolimbic deficits in adults with high psychopathy scores, with the most robust findings being reduced volumes in frontal and temporal regions including the amygdala (de Oliveira-Souza et al., 2008; Muller et al., 2008; Yang et al., 2009a, 2009b; Ermer et al., 2012; Bertsch et al., 2013). However, conflicting findings have also been presented, particularly for the hippocampus, insula, and the anterior cingulate cortex for psychopathic adults (Laakso et al., 2001; Boccardi et al., 2010; Glenn et al., 2010; Cope et al., 2012).

More recently, initial evidence has begun to emerge suggesting that deficits in regions densely connected with the frontolimbic circuitry, particularly the striatum, may also contribute to traits associated with psychopathy (Glenn and Yang, 2012; Blair, 2013). The striatum is comprised of the caudate nucleus and the putamen and has been linked to traits such as reward-seeking, stimulus-reinforcement learning, and impulsivity (Barros-Loscertales et al.,

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http://dx.doi.org/10.1016/j.pscychresns.2015.01.017
0925-4927/

2006; Cohen et al., 2009). Studies have linked psychopathy to increased sensitivity to reward and decreased sensitivity to punishment, suggesting potential abnormalities in the striatal regions that contribute to overly focus on the prospect of reward despite signals of potential later punishment (Newman and Kosson, 1986; van Honk and Schutter, 2006; Glenn et al., 2009). To date, *increased* volumes have been found in the striatal in adults with psychopathy (Glenn et al., 2009) and antisocial personality disorder (Barkataki et al., 2006), findings that are in line with the functional imaging findings of abnormal activation or connectivity with the striatum (Osumi et al., 2012; Carre et al., 2013). Therefore, it may be suggested that an overactive reward system (e.g. striatum) may further compromise the weakened regulation system (e.g., prefrontal cortex), leading to heightened psychopathic tendencies.

Despite the accumulating knowledge in the neural basis of psychopathy, studies of psychopathic traits have focused mainly on adults and the examination of psychopathic traits in children and adolescence remains scarce. By revealing structural abnormalities in regions overlap with those found impaired in adults with psychopathy, findings from studies of conduct disorder (some with comorbid callus-unemotional traits) seem to suggest a neurodevelopmental basis to psychopathy (Blair, 2006a; Gao et al., 2009). For example, reduced volumes in the amygdala, dorsolateral prefrontal cortex and orbitofrontal cortex (Kruesi et al., 2004; Sterzer et al., 2007; Boes et al., 2008; Huebner et al., 2008; Dalwani et al., 2011; Fairchild et al., 2011; Hyatt et al., 2012) have been reported in adolescents with conduct problems. In addition, callous-unemotional traits were found to correlate positively with increased volumes in the orbitofrontal cortex (De Brito et al., 2009; Fairchild et al., 2012), suggesting potential delays in brain maturation in association with certain psychopathic traits. In one study, callous-unemotional traits were also found to correlate negatively with reduced volume in the striatum (Fairchild et al., 2012), but the effect did not survive when controlling for conduct disorder symptoms.

Although findings to date have provided initial evidence suggesting abnormal brain structures associated with psychopathic traits in children and adolescents, there are notable variations among findings. One potential contribution to discrepancy among findings may be that most existing studies have been conducted on relatively small, heterogeneous samples. The aggregation of participants with a wide age range may be particularly alarming because it has been demonstrated that gray matter volumes increase in early childhood and decline in adolescence, but white matter volumes tend to increase well into adulthood (Sowell et al., 2003). The pattern of age-related changes in gray and white matter has also been shown to vary across brain regions during brain maturation (Sowell, 2002). The involvement of substance use in older participants, often co-occurring with antisocial behavior and psychopathic traits, may also complicate the matter by introducing substance-related brain changes. Furthermore, the majority of the findings are from samples with comorbid psychiatric disorders (e.g. conduct disorders, attention deficits hyperactivity disorder), making it difficult to determine to what extent previous findings can be applied to psychopathic traits in the general population.

To address these limitations in the literature, the present study included a community sample of homogeneously aged, healthy adolescents (all aged 14 years old at the time of the scanning) to examine the relationship between psychopathic tendencies and regional brain tissue volumes. We used a recently developed method of tensor-based morphometry (TBM), which allows the illustration of statistical effects on regional volumes of gray matter, white matter, and cerebrospinal fluid (CSF) across the entire brain. Specifically, global and regional differences in brain tissue volume are estimated by applying localized deformations to adjust the anatomy of each individual to match a sample-specific template. By correlating these deformation fields with psychopathic traits across the sample, very subtle morphological changes associated with psychopathic traits in adolescents can be identified, with high accuracy and sensitivity. To date, TBM has been validated and applied to study several disorders (Leow et al., 2009; Yang et al., 2012b); however, it has yet to be applied to explore patterns of brain tissue alterations associated with psychopathic traits in adolescents. Based on prior reports, we predicted that psychopathic tendencies would correlate with reduced brain tissue volumes in the fronto-limbic circuitry and increased brain tissue volumes in the striatal regions in this adolescent sample.

2. Methods

2.1. Subjects

The 108 adolescent twins (54 males and 54 females, age 14 years) included in this study were drawn from participants in the University of Southern California (USC) Risk Factors for Antisocial Behavior Twin Study (Baker et al., 2006, 2013), and comprised 27 monozygotic twin pairs (16 male and 11 female twin pairs) and 27 dizygotic twin pairs (5 male, 10 female, and 12 opposite-sex twin pairs). In brief, the USC Twin Study is a longitudinal study assessing the development of antisocial behaviors from childhood to young adulthood, which began in 2000 and now is approaching the end of fifth wave data collection. The adolescents and their families were recruited from Los Angeles County through advertisements, schools, and mothers of twins clubs. The sample is representative of the ethnic and socioeconomic diversity of the Great Los Angeles areas. The present study used data obtained from the third wave of assessment, when the twins were 14 years old, as this was the time point when magnetic resonance imaging (MRI) scans were collected. Participants were excluded if they had a history of significant head injury, major neurological, psychiatric illness, substance abuse, or contraindication to scanning (Yang et al., 2012a, Baker et al., 2013). The adolescents and their primary caregivers participated in 6–8 h of laboratory assessment at USC including a 1-h scan. Assessment of psychopathic traits was provided by caregivers, who were predominantly biological mothers ($n=50$). The remaining were biological father ($n=1$), grandmother ($n=1$), foster mother ($n=1$) and adoptive mother ($n=1$). Each child's ethnicity was determined by the ethnicity of his/her biological mother and father, as reported by the primary caregiver. The ethnicity breakdown of the sample was as follows: 36.7% Hispanic, 27.4% Caucasian, 14% Black, 4.4% Asian, 0.16% Native American, and 17.3% mixed. Both caregivers and children gave written informed consent/assent prior to the study. The study was approved by the CHLA/USC Institutional Review Boards.

2.2. Behavioral measurements

Psychopathic traits were measured using a slightly extended version of the Child Psychopathy Scale (CPS)—Revised Extended (Lynam, 1997). The CPS is a well-validated instrument for measuring psychopathic traits in children and adolescents and is composed of 14 subscales including glibness, untruthfulness, lack of guilt, callousness, impulsiveness, boredom susceptibility, manipulation, poverty of affect, parasitic lifestyle, behavioral dyscontrol, lack of planning, unreliability, failure to accept responsibility, and grandiosity. The CPS was administered to the caregivers of the adolescents in an interview form. Scores for each item were added to create a total CPS score for each individual. The internal reliabilities for the composite score have been established in previous reports (Baker et al., 2007; Bezdjian et al., 2011), and the frequency of the total CPS scores of this sample is reported in Fig. S1 (see Supplementary material). To summarize, the parent-report CPS total scores of our sample ranged from 2 to 33 (mean= 12.18, S.D.= 7.09), with males (mean=13.96, S.D.=7.92, range: 3–33) scoring higher than females (mean=10.39, S.D.=5.68, range: 2–31) ($p=0.008$). As a complementary analysis, we also categorized the participants into High-CPS (with CPS total scores in the top 20%) and Low-CPS (with CPS total scores in the low 20%) group, and the TBM results were included in Supplementary material (Fig. S2). For a subset of the sample ($n=62$), intelligence quotient (IQ) was obtained using Wechsler Intelligence Scale for Children (Wechsler, 2004). For the subsample, the intelligence mean was 100.1 for Full-Scale IQ (range: 77–129), 98.44 for Performance IQ (range 67–124) and 102.15 for Verbal IQ (range: 65–128). Further analysis showed that parent-report CPS total scores did not correlate with Full-Scale, Performance, or Verbal IQ scores (all $p>0.3$). Post hoc analyses showed that TBM results were unchanged when controlling for IQ; therefore only results controlling for whole brain volume, sex, and subject relatedness were included in this report.