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Cortical thickness correlates with impulsiveness in healthy adults

Christina Schilling [a,b,*,1], Simone Kühn [a,c,1], Alexander Romanowski [a], Florian Schubert [d], Norbert Kathmann [b], Jürgen Gallinat [a]

[a] Department of Psychiatry and Psychotherapy, Charité University Medicine Campus Mitte, St. Hedwig Krankenhaus, Große Hamburger Str. 5-11, 10115 Berlin, Germany
[b] Department of Psychology, Humboldt-Universität zu Berlin, Rudower Chaussee 18, 12489 Berlin, Germany
[c] Department of Experimental Psychology and Ghent Institute for Functional and Metabolic Imaging, Henri Dunantlaan 2, 9000 Ghent, Belgium
[d] Physikalisch-Technische Bundesanstalt, Abbestraße 2, 10587 Berlin, Germany

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ABSTRACT

Background: Impulsiveness is a central domain of human personality and of relevance for the development of substance use and certain psychiatric disorders. This study investigates whether there are overlapping as well as distinct structural cerebral correlates of attentional, motor and nonplanning impulsiveness in healthy adults.

Methods: High-resolution magnetic resonance scans were acquired in 32 healthy adults to model the gray–white and gray–cerebrospinal fluid borders for each individual cortex and to compute the distance of these surfaces as a measure of cortical thickness (CT). Associations between CT and the dimensions of impulsiveness (Barratt-Impulsiveness-Scale 11, BIS) were identified in entire cortex analyses.

Results: We observed a significant negative correlation between left middle frontal gyrus (MFG) CT and the attention BIS score (FDR $p<.05$), motor, nonplanning and total BIS score (each $p<0.001$ uncorrected). In addition, CT of the orbitofrontal (OFC) and superior frontal gyrus (SFG) were inversely correlated ($p<0.001$ uncorrected) with BIS total and motor score. Among other negative associations only one positive correlation (right inferior temporal with nonplanning score, $p<0.001$ uncorrected) was found.

Conclusions: The MFG is crucial for top-down control, executive and attentional processes. The MFG together with the OFC and SFG appears to be part of brain structures, which have previously been shown to mediate behavioral inhibition, well-planned action and attention, which are core facets of impulsiveness as measured with the Barratt-Impulsiveness-Scale.

Introduction

Impulsiveness plays a central role in modulating various aspects of ordinary life and is currently targeted by various scientific disciplines, such as personality psychology, genetics, psychiatry and neuroimaging. Impulsiveness has been described as a highly heritable personality facet (Seroczynski et al., 1999) that has been associated with eating behavior (Boschi et al., 2010), driving characteristics (Owsley et al., 2003) and the number of sexual partners (Flory et al., 2006). Besides other personality aspects, it is in particular impulsiveness, which has been shown to be an important risk factor for a number of mental health problems (Martinotti et al., 2008). Impulsive symptoms have been described as a central symptom domain in major psychiatric disorders, for instance attention-deficit/hyperactivity disorder (ADHD; Solanto et al., 2009), substance abuse (Sher et al., 2000), borderline personality disorder (Berlin et al., 2005) and suicidal behavior (Dougherty et al., 2004).

Impulsiveness has been described as a “predisposition toward rapid, unplanned reactions to internal or external stimuli without regard to the negative consequences of these reactions” (Moeller et al., 2001). It forms a core aspect of human personality (Barratt, 1994a; Cloninger, 1986) and becomes manifested in a multidimensional phenomenon. Although several sub-factors have been described in the literature, previous research on impulsiveness has primarily focused on disinhibition (Read et al., 2010). The differentiation of three subscales of impulsiveness (Patton et al., 1995) appears to dominate the recent literature (Congdon and Canli, 2008). Based on data collected from more than 700 participants Patton et al. (1995) described these distinct factors: attention (rapid shifts and impatience with complexity), motor (impetuous action) and nonplanning (lack of future orientation). The different dimensions of

Abbreviations: ADHD, Attention-deficit/hyperactivity disorder; BA, Brodman area; BIS, Barratt Impulsiveness Scale; CT, Cortical thickness; FDR, false discovery rate; fMRI, Functional magnetic resonance imaging; GM, Gray matter; IFC, Inferior frontal cortex; IFJ, Inferior frontal junction; IPC, Inferior parietal cortex; M.I.N.I., Mini-International Neuropsychiatric Interview; MFG, Middle frontal gyrus; OFC, Orbital frontal cortex; PMC, Primary motor cortex; SFG, Superior frontal gyrus; STG, Superior temporal gyrus; STN, Subthalamic nucleus; VBM, Voxel based morphometry.

* Corresponding author at: Charité Medicine Berlin, Clinic for Psychiatry and Psychotherapy, St. Hedwig Krankenhaus, Große Hamburger Str. 5-11, 10115 Berlin, Germany. Fax: +49 30 2311 2750.
E-mail address: christina.schilling@charite.de (C. Schilling).

[1] These authors contributed equally to this work.

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impulsiveness are assumed to have different neural substrates (Barratt, 1994b; Bechara and Damasio, 2005).

The question of which neurobiological substrates underlie impulsiveness has stimulated a growing body of neuroimaging research, mainly comprising functional magnetic resonance imaging (fMRI) studies. The narrow set of task paradigms applied in fMRI investigations, such as the Go/No-Go and stop-signal tasks, may account for their evidence being limited to inferences on aspects of motor impulsiveness (Congdon and Canli, 2008). Those studies have put forward particularly the right inferior frontal cortex (IFC) and the subthalamic nucleus (STN) as the neural correlates of behavioral inhibition (Congdon and Canli, 2008). The inferior frontal cortex is essential for controlling behavioral inhibition and the STN plays a central role in braking ongoing motor commands (Nambu et al., 2002). Interestingly, Asahi et al.(2004) have found a negative association between prefrontal activation during response inhibition (Go/No-Go task) and the subtrait motor impulsiveness (BIS 11) in a healthy sample. Similarly, Horn et al.(2003) have described an inverse correlation between trait impulsiveness (BIS sum score) and activation in the superior frontal gyrus (SFG) as well as the temporoparietal association area during response inhibition (Go/No-Go task) in healthy adults.

Only a fraction of neuroimaging studies on impulsiveness has used structural imaging. Previous structural MRI studies on impulsiveness-related disorders have yielded heterogeneous findings. For instance, while subscales of the Barratt-Impulsiveness-Scale (BIS) were reported to be positively correlated with gray matter (GM) of the bilateral orbital frontal cortex (OFC) in a group of non-psychotic psychiatric clients (Antonucci et al., 2006), for the same region a volume deficit was observed in depressive patients with impulsiveness related suicide attempts compared to controls (Monkul et al., 2007). Furthermore, in an ADHD sample Carmona et al.(2005) have shown GM volume deficits in frontostriatal regions, the cerebellum, left cingulate, bilateral parietal and temporal cortex compared to normal controls. Both negative (left middle frontal gyrus, MFG) and positive (posterior cingulate, ventral striatum) correlations with impulsiveness have been found in recently detoxified substance users (Schwartz et al., 2010). However, studying heterogeneous clinical samples causes extra variance associated with disorder and medication specific confounds, which might also account for the divergent results reported by structural MRI studies as discussed above.

Structural imaging studies on impulsiveness' morphological correlates in healthy samples are rare. To our knowledge, up to now four studies have been published on associations with GM volume, out of those only three ones focused on trait impulsiveness: A positive correlation with GM volume in superior and middle frontal regions was shown (Gardini et al., 2009), while all other studies reported an inverse relationship. External behavioral ratings of impulsiveness were found to be negatively associated with right ventromedial prefrontal cortex volume (Boes et al., 2009). In particular, the bilateral orbitofrontal cortex GM volume was reported to be inversely correlated with the BIS total score (Matsuo et al., 2009). In sum, previous structural MRI studies on the neural substrates of impulsiveness in healthy samples have either focused on broader personality concepts than the specific facet of impulsiveness (Gardini et al., 2009) or have not covered subtraits of impulsiveness (Kumari et al., 2009). Even though Matsuo et al.(2009) focused on all three empirically based subtraits of impulsiveness (Patton et al., 1995), they could not identify any structural correlate of attentional impulsiveness. Furthermore, none of those investigations has applied alternative measures such as cortical thickness (CT), albeit recent structural studies emphasize the relevance of the thinning of the cortical surface for impulsiveness-related disorders such as ADHD (Almeida et al., 2010; Batty et al., 2010) and substance use (Lawyer et al., 2010; Lopez-Larson et al., 2011).

The present study aimed to explore the structural substrates of facets of impulsiveness using surface-based morphology analyses applying FreeSurfer software. This fully automated tool has successfully been applied in a wide range of empirical research (Greene and Killiany, 2010; McCauley et al., 2010; Raj et al., 2010). Particularly CT has been suggested to be a more sensitive parameter with a higher signal-to-noise ratio compared to voxel based morphometry (Choi et al., 2008; Dickerson et al., 2008; Hutton et al., 2009; Salat et al., 2004). Although, there is some evidence for frontal structures playing a decisive role in impulsiveness, previous results in healthy samples are heterogeneous and lack findings on CT. Hence, our aim was to identify structural correlates of impulsiveness by means of an exploratory approach using CT in entire cortex analyses in healthy adults. In addition, smoking status was controlled for, since it has been shown to affect brain morphology in otherwise healthy subjects (Gallinat et al., 2006; Kuhn et al., 2010). Operationalizing impulsiveness by means of the BIS scale provided the chance to reflect both the common trait, thought to underlie this construct (Barratt, 1994b; Cloninger, 1986), and its multidimensional character (attentional, nonplanning and motor impulsiveness).

Material and methods

Participants

We recruited subjects by means of advertisements in local newspapers. Thirty-two adults (*M* 35.2 years, *SD* 10.5, 18 females) took part in the present study. A psychiatrist screened participants for exclusion criteria using the Mini-International Neuropsychiatric Interview (M.I.N.I.; Sheehan et al., 1998). Any axis I disorder including drug abuse or dependence led to exclusion from the study. In addition, any volunteer with a family history (first degree) of Axis I disorders or medical conditions was excluded. Besides smoking (11 current smokers, 5 former smokers) no significant substance use was reported. All procedures of this study were approved by the ethics committee of the Charité University Medicine Berlin. Prior to testing, all participants were provided with a complete description of the assessment. Subsequently their written consent was obtained.

Impulsiveness measure

Participants were asked to fill in the BIS 11, a self-report questionnaire designed to measure impulsiveness (German version, Preuss et al., 2008). Besides the total score of all 30 items three subscale scores can be computed, which have previously been identified by means of factor analysis: attentional, motor and nonplanning impulsiveness (Patton et al., 1995). All items are answered on a 4-point Likert-scale (*Rarely*/*Never*; *Occasionally*; *Often*; *Almost always*/*Always*). Higher scores signify higher impulsiveness.

MR imaging

Structural MRI was performed on a 3-Tesla scanner (MEDSPEC 30/100, Bruker Biospin, Ettlingen, Germany). T1-weighted images were acquired using MDEFT (modified driven equilibrium Fourier transform, with TE = 3.8 ms, TR = 20.53 ms; TI = 550 ms, nominal flip angle 30°; 128 contiguous slices, 1.5 mm thick; 1-mm in-plane (x–y) resolution).

Image analysis

Anatomical images were visually inspected for motion artifacts and gross structural abnormalities. CT was estimated from the T1-weighted magnetic resonance images using FreeSurfer software, a set of automated tools for reconstruction of brain cortical surface (Fischl and Dale, 2000). Accordingly, the T1-weighted images were used to segment cerebral white matter (Dale et al., 1999) and to estimate the gray–white matter interface. This gray–white matter estimate was