Neuropsychologia 47 (2009) 599–603

Contents lists available at ScienceDirect

Neuropsychologia

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

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The complex minds of teenagers: Neuroanatomy of personality differs between sexes

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ARTICLE INFO

Article history:
Received 29 July 2008
Received in revised form 7 October 2008
Accepted 15 October 2008
Available online 25 October 2008

Keywords:
Neuroticism
Extraversion
MRI
VBM
CTA
Sex differences
Adolescents

ABSTRACT

Extraversion and neuroticism influence behaviour and mood. Extreme expressions of these personality traits may predispose individuals to developing chronic functional pains and mood disorders that predominantly affect women. We acquired anatomical MRI scans and personality scores from healthy male and female adolescents and measured gray matter volume (GMV) and cortical thickness to test the hypothesis that neuroticism and extraversion contribute to sex differences in fronto-limbic cortical development during a crucial period of social and biological maturation. In females, extraversion correlated negatively with medial frontal gyrus GMV and neuroticism correlated positively with subgenual anterior cingulate cortex GMV and cortical thickness. Interestingly, correlations between GMV and personality in males showed an opposite effect. Given the association of these cortical areas with social cognition and emotional processing, we suggest that a neuro-maturational divergence during adolescence accounts for the higher prevalence of specific chronic pains and mood disorders in females.

1. Introduction

Personality is an important construct that is unique to each individual. The five factor model describes five distinct personality traits (Costa & McCrae, 1992). Of the five, neuroticism and extraversion are of particular interest as they are believed to be crucial for the development of healthy social interactions, and have an over-arching influence on affect and mood. Extraversion is characterized by an increased tendency to be optimistic and experience positive emotions, and enhanced sociability. Conversely, neuroticism is defined as having an increased tendency to worry and to experience psychological distress, accompanied by negative affect and sensitivity to negative cues. These two personality traits are strongly associated with emotional experience and may modulate emotion-evoked brain activity (Canli et al., 2001). Also, neuroticism may predispose individuals to develop chronic functional pains (Tanum & Malt, 2001) or mood disorders such as depression and anxiety (Bienvenu et al., 2001; Goodwin & Gotlib, 2004). Interestingly, both the levels of neuroticism and the prevalence rates of anxiety and mood disorders are higher in females than males (Goodwin & Gotlib, 2004; Leach, Chistensen, Mackinnon, Windsor, & Butterworth, in press). Moreover, the prevalence of depression increases in early adolescence (Saluja et al., 2004), and at this time females begin to have a higher incidence rate than males (Angold, Costello, & Worthman, 1998). Neuroticism can also enhance catastrophic thoughts toward pain, which may lead to the emergence and persistence of chronic pain syndromes as well as somatisation disorders (Goubert, Crombez, & Van Damme, 2004).

Functional neuroimaging studies have demonstrated that task-evoked brain activity varies with neuroticism and extraversion scores in the prefrontal and cingulate cortex (Canli et al., 2001; Johnson et al., 1999; Kim, Hwang, Park, & Kim, 2008; Bush, Luu, & Posner, 2000; Haas, Omura, Constable, & Canli, 2007). Recently, extraversion and neuroticism were also shown to impact structural features of the prefrontal cortex in adult and elderly populations

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doi:10.1016/j.neuropsychologia.2008.10.014

(Wright et al., 2006; Wright, Feczko, Dickerson, & Williams, 2007). To date however, it is not known whether these personality traits impact brain structure in adolescence, a critical period of development where a divergence in neuromaturation between the sexes becomes more apparent.

It is clear that brain structure, function and behaviour are intimately intertwined. A complete understanding of the relationship between these three domains is critical to advance our knowledge of mood and chronic pain disorders. In the present study we used voxel-based morphometry (VBM) and cortical thickness analysis (CTA) to measure links between brain development, personality and sex. Specifically, we tested whether neuroticism and extraversion impact frontal–limbic structures in adolescence and the effect of sex on this relationship.

2. Methods and materials

2.1. Subjects and questionnaires

Thirty-five right-handed healthy adolescents (15 males, 20 females; 16–17 years old) consented to procedures approved by the University Health Network Research Ethics Board. All subjects were right-handed, spoke English as their primary language and had no prior history of psychiatric or neurological disorders. The 60 item NEO-FFI (Costa & McCrae, 1992) was administered to all subjects to assess five personality traits: neuroticism, extraversion, agreeableness, openness and conscientiousness. The Pain Catastrophizing Scale (PCS), a 13 item questionnaire, was also administered (Sullivan, Bishop, & Pivik, 1995).

2.2. Brain imaging

Participants underwent structural MR imaging with a 3.0 T GE scanner (GE Medical Systems, Milwaukee, Wisconsin). A T1-weighted 3D IR-SPGR anatomical scan (TE = 5 ms, TR = 25 ms, 45° flip) acquired 124 1.5 mm thick sagittal images (FOV = 24, matrix = 256 × 256).

2.3. Voxel-based morphometry

Voxel-based morphometry was implemented in SPM5 using the VBM5 toolbox (http://dbm.neuro.uni-jena.de/vbm). Each subject's T1-weighted anatomical scan was normalized to the International Consortium for Brain Mapping (ICBM) template of healthy controls and segmented using the unified segmentation algorithm in SPM5. Segmented gray matter images underwent Jacobian modulation to adjust for the effects of spatial normalization. Images were smoothed (10 mm FWHM kernel) and an absolute threshold mask of 0.20 was applied to avoid partial volume effects. Each subject's final gray matter image was then entered into a voxelwise analysis of covariance (ANCOVA) with neuroticism, extraversion, and pain catastrophizing scores, coded according to sex using the over-parameterized method. Total intracranial volumes were entered as a covariate to control for between-subject variance in gross brain size. Main effects for each covariate and interaction effects of sex on the remaining covariates were assessed using t-contrasts. In stage 1, we used the Wake Forest University (WFU) Pick Atlas (Maldjian, Laurienti, Kraft, & Burdette, 2003) to define a region of interest (ROI) consisting of the frontal and limbic lobes, and analyses were performed at an uncorrected threshold of $p < 0.001$ with a cluster threshold of $k > 200$. In stage 2, specific ROIs of interest based on previous functional and structural studies of personality in adults and the elderly (Haas et al., 2007; Wright et al., 2006, 2007) were examined at a corrected threshold of $p < 0.05$, using the false discovery rate (FDR) method to correct for multiple comparisons. The ROIs included the middle frontal gyrus, medial frontal gyrus,

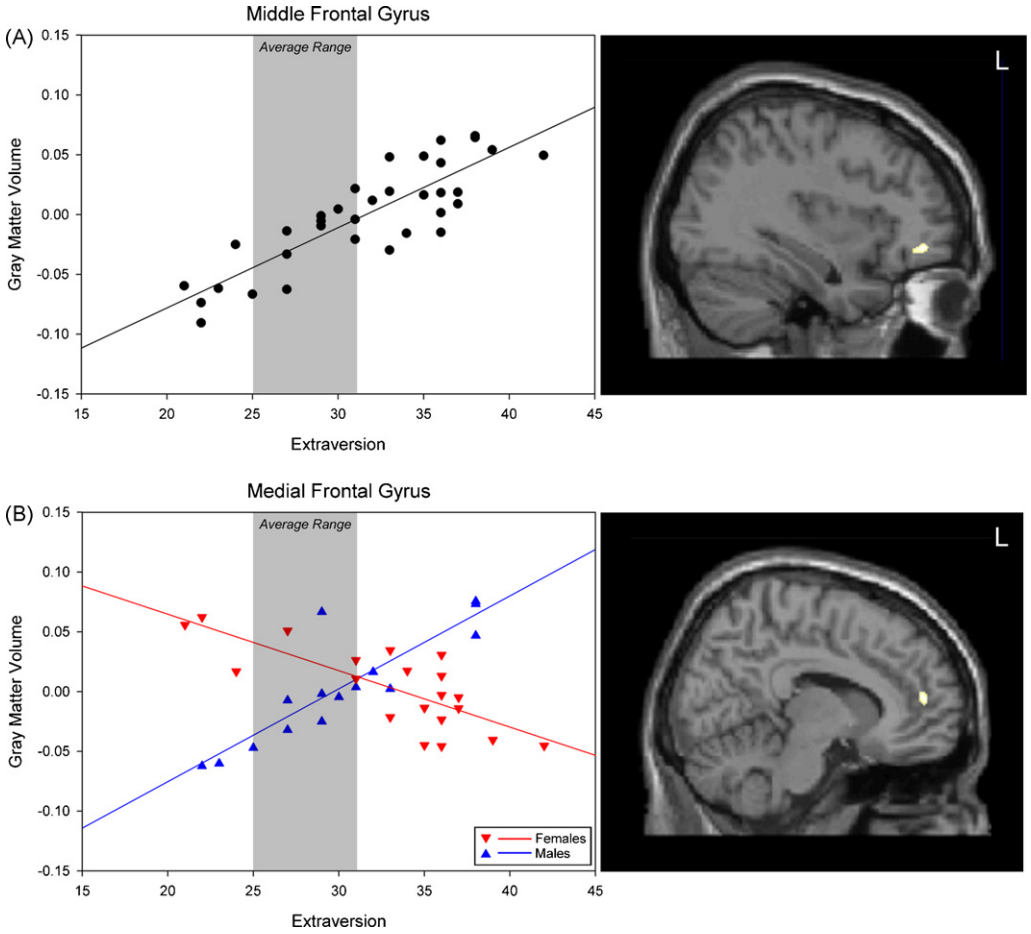

Fig. 1. Extraversion is related to gray matter volume in the left middle and medial frontal gyri. (a) In the left middle frontal gyrus, extraversion is positively correlated to GMV (corrected $p < 0.05$), regardless of sex ($r = 0.86$, $p < 0.001$). (b) In the left medial frontal gyrus, sex modulates the effect of extraversion on GMV (corrected $p < 0.05$). Extraversion is positively correlated to GMV in males ($r = 0.87$; $p < 0.001$) and negatively in females ($r = -0.77$; $p < 0.001$). GMV values are mean-centred. Shaded region indicates the average range of extraversion scores in the general population (see NEO-FFI (Costa & McCrae, 1992)).

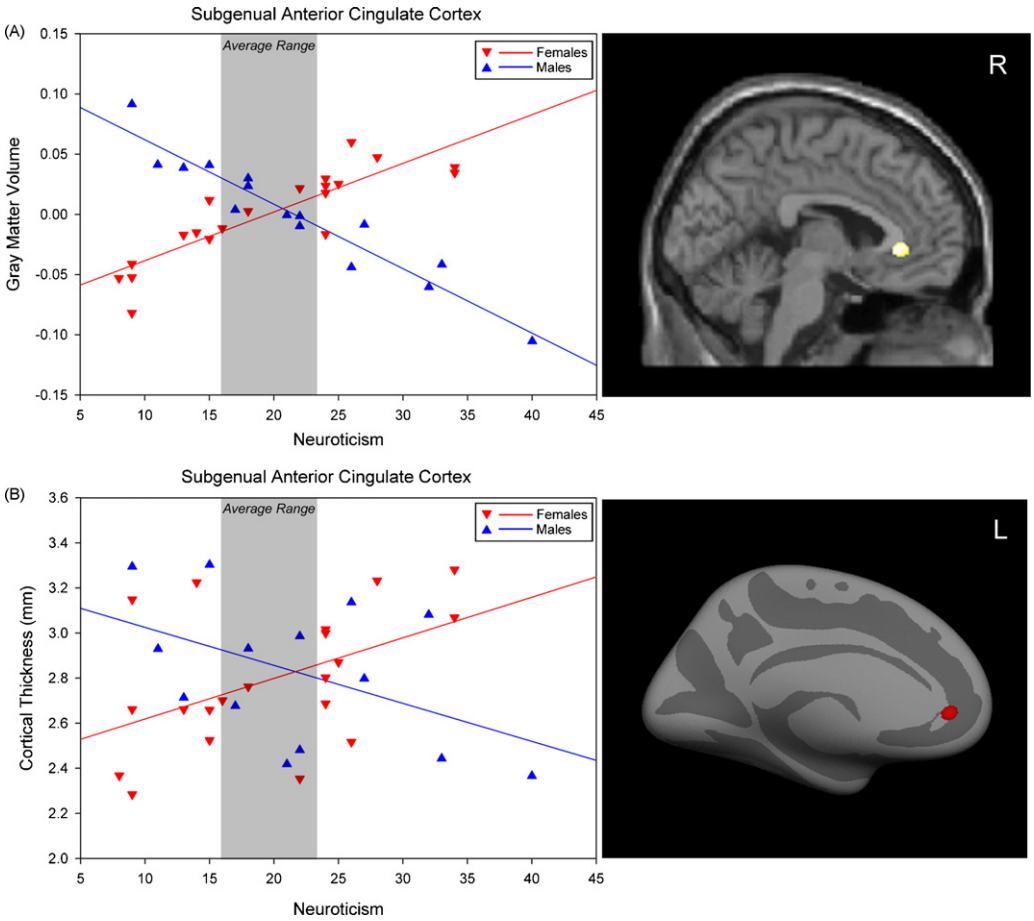

Fig. 2. Sex modulates the effect of neuroticism on gray matter in the subgenual anterior cingulate cortex. Neuroticism is positively correlated with (a) gray matter volume and (b) cortical thickness (corrected $p < 0.05$) in females, but negatively in males. The correlation was significant in VBM (bilateral; females: $r = 0.87$; $p < 0.001$; males: -0.96; $p < 0.001$) and CTA analyses (left; females: $r = 0.48$, $p < 0.05$; males: $r = -0.47$, $p > 0.05$). GMV values are mean-centred. Shaded region indicates the average range of neuroticism scores in the general population (see NEO-FFI (Costa & McCrae, 1992)).

and subgenual anterior cingulate cortex (sgACC). Since the WFU Pick Atlas does not include a predefined ROI for the sgACC, a sphere ROI of 5 mm radius was approximated at the centre of this region in the Pick Atlas (0, 32, −3; Talairach coordinates).

2.4. Cortical thickness analysis

To quantify the findings obtained in the VBM analysis, CTA was implemented in Freesurfer (Fischl & Dale, 2000). One subject was excluded from this analysis due to Freesurfer's inability to properly segment the image volume. All other subjects' MRIs were registered to a Talairach template and segmented to identify gray-white matter boundaries. Inner and outer cortical surfaces were generated from these boundaries and the distance between them calculated. Each subject's surface map of thickness values was aligned to Freesurfer's default average surface map according to cortical folding pattern and data smoothed in the common surface space (10 mm kernel). Statistical analyses were identical to the ones performed in the VBM analyses, excluding the total intracranial volume measurement. Masks defined by Freesurfer's built in atlas were used to capture the ROI's identified in the VBM analysis.

2.5. Second level ROI analysis

To better visualize the significant findings and attain correlation values, scatter plots were created and simple regressions performed on gray matter volume (GMV) and cortical thickness data extracted from ROIs identified by the positive findings in the previous ANCOVAs. Mean-centred and adjusted values for GMV were obtained from the VBM analysis.

3. Results

There were no statistically significant differences in neuroticism (females mean ± standard deviation: 19.6 ± 8.1; males 21.6 ± 8.7), extraversion (females 30.1 ± 5.1; males 33.1 ± 5.6), and pain catastrophizing scores (females 21.8 ± 10.2; males 21.1 ± 8.4) between males and females ($p > 0.1$), nor were these personality scores significantly correlated to each other ($p > 0.1$). Thus, differences in the distribution of personality scores did not contribute to the following gray matter findings.

Extraversion was related to GMV in both the left middle and medial frontal gyri. An overall positive main effect was identified for extraversion with GMV in the left middle frontal gyrus (BA 11), regardless of sex (Talairach coordinates −36, 38, −10; $k = 744$; $r = 0.86$; Fig. 1a). Interestingly, an interaction effect between extraversion and sex was found in BA 10/32 of the left medial frontal gyrus (Talairach coordinates −12, 50, 10; $k = 488$; Fig. 1b). Specifically, extraversion was positively related to gray matter volume in males ($r = 0.87$; $p < 0.001$), but negatively related in females ($r = -0.77$; $p < 0.001$).

Although no significant main effect was found for neuroticism, an interaction effect was found between neuroticism and sex bilaterally in the subgenual portion (border between BA 25 and 24) of the anterior cingulate cortex (peak voxel Talairach coordinate 3, 32, −3; $k = 230$; Fig. 2a). Specifically, neuroticism was positively correlated to GMV in females ($r = 0.87$; $p < 0.001$), but negatively correlated in males ($r = -0.96$; $p < 0.001$).

In addition, the CTA confirmed this relationship in the left sgACC in BA 32/24 (Talairach coordinate −8, 40, −2; uncorrected $p < 0.003$; Fig. 2b). Neuroticism was positively correlated to cortical thickness in females ($r = 0.48$; $p < 0.05$), but negatively correlated in

males ($r = -0.47$; $p > 0.05$). The discrepancy between the precise neuroanatomical location of the VBM versus CTA finding here may be explained by differences in the registration targets, and the conversion between not only these atlases, but also volume and surface space. No other confirmatory or additional new results were found for either neuroticism or extraversion with the CTA method. There were no supra-threshold clusters found for the PCS contrasts for main effect or interaction with sex.

4. Discussion

Our data show for the first time that personality traits of extraversion and neuroticism impact frontal and limbic structures in adolescents, respectively. Moreover, we have demonstrated strong interactions between sex and personality on neuroanatomy in adolescents. This may reflect differences in how males and females mature socially and could influence their neuropsychology as adults as well as a predisposition to develop chronic functional pains or mood disorders.

Extraversion correlates with brain activation (medial prefrontal cortex) to positive stimuli in healthy women (Canli et al., 2001). Electrophysiological scalp recordings have revealed that greater left versus right hemisphere activity is associated with an increase in tendency towards positive affect and increased approach behaviour (Tomarken, Davidson, Wheeler, & Doss, 1992). We found comparable regional and laterality effects as there was a positive main effect between the extraversion personality trait and the left middle frontal gyrus, regardless of sex. Increased GMV in the left but not right middle frontal gyrus may thus be related to an enhanced processing of positive cues, and thereby with an increased positive affect and seeking of social interaction that extraverts are known for.

Since highly extraverted individuals are more inclined to be sociable, extraversion may be associated with social cognition. Social cognition tasks such as self-knowledge, person-knowledge, and mentalizing activate the medial prefrontal cortex (Amodio & Frith, 2006). However, these task-related activations decrease in the transition from adolescence to adulthood. We found that extraversion is negatively correlated with gray matter in the left medial frontal gyrus in females, but positively correlated in males. Gray matter levels are known to peak earlier during adolescence in females compared to males (Blakemore, 2008), and so our finding may point to earlier neuromaturation in females as opposed to males. We propose that females who are highly extraverted become proficient in social cognition tasks and would thus exhibit an earlier decline in dependence on the medial prefrontal cortex—manifested by reductions in GMV. It has been suggested that a decrease in gray matter volume could occur due to synaptic reorganization, from either a decrease in excitatory neurons, inhibitory interneurons, glia or neuropil (Wright et al., 2006).

The prevalence of depressive disorders becomes higher in females at approximately 13 years of age (Angold et al., 1998). Neuroticism and catastrophizing have been proposed as contributing to this sex-related disparity (Garnefski, Legerstee, Kraaij, Van Den Kommer, & Teerds, 2002; Goodwin & Gotlib, 2004). Our findings support this interpretation as neuroticism scores for females had a strong positive correlation with gray matter volume in the sgACC, whereas males showed the converse relationship. Hence, it appears as though sex modulates the effect of neuroticism on gray matter structure in sgACC. Bush et al. (2000) have described this area to be a part of the affective subdivision of the cingulate cortex, which is known to be anatomically connected to other emotional processing areas such as the anterior insula, orbitofrontal cortex, amygdala, nucleus accumbens, hippocampus, hypothalamus, and periaqueductal gray (Devinsky, Morrell, & Vogt, 1995). Although previous structural studies have found that depressive symptoms are associated with reductions in sgACC (Drevets, Savitz, & Trimble, 2008), our findings are in line with some functional studies. In fact, sgACC activity has been associated with negative mood states (George et al., 1995; Mayberg et al., 1999), and successful treatment in patients suffering from depression leads to decreased activity in this area (Johansen-Berg et al., 2008). In light of these findings, increased gray matter may be associated with enhanced levels of cortical processing and thereby increase the sensitivity to negative cues that might eventually lead to depressive symptoms.

Acknowledgements

K.D.D. is a Canada Research Chair in Brain and Behaviour. This work was supported from CRC funds and a CIHR New Emerging Team grant. We thank Adrian Crawley, Hien Tran, and Geoff Pope for technical assistance.

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