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# The Five Factors of Personality and Regional Cortical Variability in the Baltimore Longitudinal Study of Aging

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**Abstract:** Although personality changes have been associated with brain lesions and atrophy caused by neurodegenerative diseases and aging, neuroanatomical correlates of personality in healthy individuals and their stability over time have received relatively little investigation. In this study, we explored regional gray matter (GM) volumetric associations of the five-factor model of personality. Eighty-seven healthy older adults took the NEO Personality Inventory and had brain MRI at two time points 2 years apart. We performed GM segmentation followed by regional analysis of volumes examined in normalized space map creation and voxel based morphometry-type statistical inference in SPM8. We created a regression model including all five factors and important covariates. Next, a conjunction analysis identified associations between personality scores and GM volumes that were replicable across time, also using cluster-level Family-Wise-Error correction. Larger right orbitofrontal and dorsolateral prefrontal cortices and rolandic operculum were associated with lower Neuroticism; larger left temporal, dorsolateral prefrontal, and anterior cingulate cortices with higher Extraversion; larger right frontopolar and smaller orbitofrontal and insular cortices with higher Openness; larger right orbitofrontal cortex with higher Agreeableness; larger dorsolateral prefrontal and smaller frontopolar cortices with higher Conscientiousness. In summary, distinct personality traits were associated with stable individual differences in GM volumes. As expected for higher-order traits, regions performing a large number of cognitive and affective functions were implicated. Our findings highlight personality-related variation that may be related to individual differences in brain structure that merit additional attention in neuroimaging research. *Hum Brain Mapp 34:2829–2840, 2013.* 

**Key words:** individual differences; trait; neuroticism; extraversion; openness; agreeableness; conscientiousness; anterior cingulate; orbitofrontal cortex; frontopolar cortex

Additional Supporting Information may be found in the online version of this article.

Conflict of Interest: Paul Costa receives royalties for the NEO-PI-R.

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## INTRODUCTION

There is wide range interpersonal variation in cognitive and affective processing. Individual differences in cognitive task performance are associated with differential recruitment and efficiency of implicated brain networks [Kosslyn et al., 2002; Plomin and Kosslyn, 2001]. Similarly, variation in affective processing, including both trait and state-level variation, may result from differential recruitment of affective networks [Drabant et al., 2009]. In addition, it is increasingly being recognized that persistent individual differences may reflect structural variation in the neural substrates underlying these behaviors [Erickson et al., 2010; Roppongi et al., 2010; Takeuchi et al., 2010].

Personality is a set of enduring, pervasive, and distinctive patterns of thoughts, feelings, and actions that occur in response to particular situational demands [Mischel, 2004]. To explain the daunting variability in human personality, hierarchical models of trait structure have emerged that combine specific into higher-order traits. Among these, the five factor model (FFM) demonstrates temporal stability and consensual validity, is pervasive in psychological theory and lay vocabulary [Goldberg, 1990], has strong neurobiological basis and universality (across age, race, sex, and cultures) [Costa and McCrae, 1992; McCrae and Costa, 2003] and emerges from the factor analysis of multiple other personality inventories [Markon et al., 2005]. Moreover, the revised NEO-Personality Inventory (NEO-PI-R), one operationalization of the FFM, has been extensively used in psychological and biomedical research [Costa and McCrae, 1992]. The NEO-PI-R has a robust factor structure that has been replicated in more than 50 cultures [McCrae et al., 2005] and has been shown to be stable over time [Terracciano et al., 2006]. Within the NEO-PI-R framework, each of the major five factors of personality, neuroticism (N), extraversion (E), openness to experience (O), agreeableness (A), and conscientiousness (C), emerge as the sum of more fundamental traits reflecting intrapsychic, attitudinal, experiential, interpersonal, and motivational individual differences respectively. The five factors influence cognitive [Gusnard et al., 2003; Kumari et al., 2004] and affective [Canli, 2004; Canli et al., 2004; Haas, et al., 2006b] processing, social cognition, and behavior [Lebreton et al., 2009].

The heritability [Bouchard and Loehlin, 2001], temporal stability, and universality [McCrae et al., 2005; Terracciano et al., 2006] of the Factors imply that personality may be an emergent property of the brain's structural and functional organization. Multiple prior structural and functional neuroimaging studies have reported structural and functional neural correlates of these traits. For instance, personality traits have been associated with regional patterns of brain activation and blood flow during performance of trait-dependant tasks [Canli, 2004; Canli et al., 2004; Gusnard et al., 2003; Haas et al., 2006a,b; Kumari et al., 2004] or during rest [Johnson et al., 1999; Kim et al., 2008; O'Gorman et al., 2006; Sugiura et al., 2000; Tomarken et al., 1990]. Further evidence for a link between personality and structural brain organization is provided by personality changes seen in neurodegenerative diseases [Pocnet et al., 2011; Rankin et al., 2004, 2006; Sollberger et al., 2009]. Moreover, several associations of cortical variability with personality have been reported [Blankstein et al., 2009; DeYoung et al., 2009; Wright et al., 2006, 2007].

Findings in these studies have shown a low degree of correspondence. Considering E and N alone, we note little replicability in their association with specific prefrontal cortex (PFC) and subcortical regions across studies [Blankstein et al., 2009; Omura et al., 2005; Roppongi et al., 2010; Wright et al., 2006, 2007]. This inconsistency may be partly due to studying different populations, for example, teenagers [Blankstein et al., 2009] versus young [Omura et al., 2005; Wright et al., 2006] or older adults [Wright et al., 2007]. It may also be partly attributable to implementing divergent analytical approaches, such as implementing a common general linear model (GLM) for all Factors versus implementing a separate GLM for each Factor and performing regions-of-interest (ROIs)-based versus whole-brain analysis. While limiting the analysis to ROIs based on solid a priori hypotheses is a valid approach, it presupposes a rather mature field and certain already established facts upon which novel hypotheses can be based. In our opinion, this requirement has yet to be fulfilled for neuroanatomical studies of personality. Therefore, our preferred methodological approach is to conduct exploratory voxel-wise studies in large cohorts, employing strict statistical criteria and correction for multiple comparisons. A similar approach is being taken in genetics, in which exploratory genome-wide association studies employ strict statistical criteria to identify associations, which may be confirmed subsequently with other targeted analyses. To our knowledge, the only study to date that has adopted such an approach is the one by DeYoung et al. [2010].

In this study, we explored how regional variability in gray matter (GM) is associated with the five factors in a relatively large prospectively evaluated cohort of older adults. The analysis we conducted was exploratory and implemented strict statistical criteria and correction for multiple comparisons. Moreover, we were able to replicate our findings based on longitudinal data from the same subjects.

## SUBJECTS, MATERIAL, AND METHODS

The sample included 45 men and 42 women (91% Caucasians; years of education = 16.20 +/− 2.86) who had taken the NEO-PI-R and had brain MRI at two time points with an average interval of 2 years. Participants were drawn from the neuroimaging study of the Baltimore Longitudinal Study of Aging (BLSA) [Resnick et al., 2000]. At enrollment into the imaging study, participants were 72 (+/−7.7) years old and were free of CNS disease, severe cardiovascular disease, severe pulmonary disease, and

metastatic cancer. Participants completed a battery of neuropsychological tests: cognitive status was assessed using the Mini Mental State Exam, memory using the California Verbal Learning Test and Benton Visual Retention Test, visuospatial function using the Card Rotations Test, verbal fluency using the Letter and Category fluency tests, attention and executive function using the Trail Making Test A and B.

Personality traits were assessed with the NEO-PI-R form S (completed by the participants), a comprehensive measure of the FFM [Costa and McCrae, 1992]. Participants were blind to data from the previous visit when taking the NEO-PI-R for the second time. The NEO-PI–R consists of 240 items answered on a 5-point Likert format ranging from strongly disagree to strongly agree. Raw scores were standardized as T-scores ($M = 50$, SD $= 10$) using combined-sex norms reported in the manual [Costa and McCrae, 1992]. When participants filled the NEO-PI-R for the second time, they were kept blind to their prior answers. Stability of the five factors across the 87 participants was assessed with a double-entry intraclass correlation.

MRI scans were acquired on a GE Signa 1.5T scanner (Milwaukee, WI) using a high-resolution volumetric spoiled-grass axial series (repetition time = 35 msec, echo time = 5 msec, field of view = 24 cm, flip angle = 45°, matrix = 256 × 256, number of excitations = 1, voxel dimensions 0.94 × 0.94 × 1.5 mm). The images were preprocessed according to previously validated and published techniques [Davatzikos et al., 2001; Goldszal et al., 1998]. They were corrected for head tilt and rotation and were reformatted parallel to the anterior-posterior commissure plane. Extracranial tissue was removed using a semi-automated procedure followed by manual editing. The cerebellum and brainstem below the rostral midbrain level were also removed to improve the accuracy of segmentation and normalization. Next, images were segmented into GM, white matter (WM), and cerebrospinal fluid (CSF), using a brain tissue segmentation method proposed in [Pham and Prince, 1999], followed by high-dimensional image warping [Shen and Davatzikos, 2002] to a standardized coordinate system, a brain atlas (template) aligned with the MNI coordinate space [Kabani et al., 2008]. Tissue-preserving image warping was used to create regional volumetric maps (RAVENS maps) for GM, WM, and CSF separately [Davatzikos et al., 2001; Goldszal et al., 1998]. If the image warping transformation registering an individual scan with the template applies an expansion to a GM structure, the GM density of the structure decreases accordingly to insure that the total GM volume is preserved. Conversely, a RAVENS value increases during contraction, if tissue from a relatively larger region is compressed to fit a smaller region in the template [Misra et al., 2009]. Therefore, RAVENS values in the template's space are directly proportional to the volume of the respective structures in the original brain scan and regional volumetric measurements and comparisons can be performed via measurements and comparisons of the respective RAVENS maps [Misra et al., 2009]. The RAVENS approach has been extensively validated [Davatzikos et al., 2001; Goldszal et al., 1998] and applied to a variety of studies [Misra et al., 2009; Resnick et al., 2000]. It uses a highly conforming high-dimensional image-warping algorithm that captures fine structural details. Moreover, it uses tissue-preserving transformations, which ensures that image warping preserves the amount of GM tissue present in an individual's scan, thereby allowing for local volumetric analysis [Misra et al., 2009].

Intracranial volume (ICV) was calculated using the template-warping algorithm modified for head image registration [Driscoll et al., 2009]. GM RAVENS maps were smoothed using a 12-mm full-width at half-maximum filter; the relatively large smoothing kernel was selected because complex personality traits are more likely to be associated with larger cortical areas.

For statistical inference, we used VBM methodology [Ashburner and Friston, 2000] as implemented in SPM8 (Wellcome Department of Imaging Neuroscience, Institute of Neurology, UCL). We fitted the data into a GLM, according to the following equation:

$$\begin{aligned} y = {} & \beta_1 T_1 + \beta_2 T_2 + \beta_3 (N^* T_1) + \beta_4 (N^* T_2) + \beta_5 (E^* T_1) \\ & + \beta_6 (E^* T_2) + \beta_7 (O^* T_1) + \beta_8 (O^* T_2) + \beta_9 (A^* T_1) + \beta_{10} (A^* T_2) \\ & + \beta_{11} (C^* T_1) + \beta_{12} (C^* T_2) + \beta_{13} (\mathrm{Age}^* T_1) + \beta_{14} (\mathrm{Age}^* T_2) \\ & + \beta_{15} (\mathrm{Sex}^* T_1) + \beta_{16} (\mathrm{Sex}^* T_2) + \beta_{17} (\mathrm{Education}^* T_1) \\ & + \beta_{18} (\mathrm{Education}^* T_2) + \beta_{19} ICV \end{aligned}$$

where $y$ is the observation vector (intensity value of each RAVENS voxel) over all participants, βs are the coefficients associated with each predictor, at time points 1 and 2 ($T_1$ and $T_2$), the *N, E, O, A,* and *C* domain scores, age (in years), sex, education (in years) and ICV. The ICV from the initial scanning was used for global normalization at both times to avoid potential bias of ensuing brain atrophy on ICV estimation. Global normalization for ICV was performed to identify regions where the trends in GM volume differ from global variation in intracranial size. From the results of the GLM, a *t*-test was computed for each voxel and statistical parametric maps were created with a significance threshold of $P < 0.001$.

Subsequently, a conjunction analysis was performed to identify areas of spatial overlap between the statistical maps from the two time points. (For an illustration of how the conjunction analysis was performed, we refer to Supporting Information Fig. 1, which contains the statistical parametric maps for the contrast of positive association with *O* for $T_1$, $T_2$ and their conjunction.) The statistical parametric maps from the conjunction analysis were then subjected to correction for multiple comparisons using the theory of Gaussian random fields. Specifically, we performed Family Wise Error (FWE)-correction at the cluster-

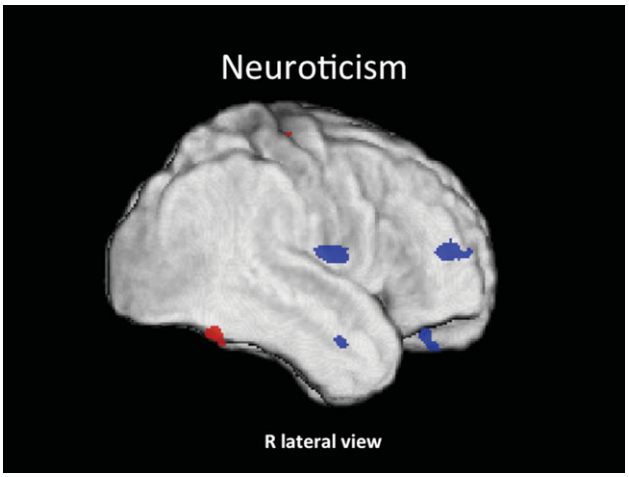


**Figure 1.**
Neuroticism: Conjunction SPM T-map of positive (red) and negative (blue) correlations of N rendered on the subjects' average GM image ($z > 3.5$).

level adopting a significance threshold of $P < 0.05$ for corrected results.

SPM creates a separate spatial map of β coefficients (or beta weights) for each regressor during model estimation (beta_00*.img files). The β coefficient for a particular regressor represents the slope of the regression of voxel values (in this case, GM RAVENS values, which represents GM volumes contained in each voxel) by this variable (in this case, *N*, *E*, *O*, *A*, or *C* Factor T-scores). Therefore, reported β coefficients are expressed in (GM RAVENS voxel value)/(NEO Factor T-score) units. They are a meaningful estimate of effect size, since they represent the change in GM volume contained in a voxel for a change of 1/10 of a standard deviation of a NEO Factor. To provide an estimate for the effect of each regressor on reported clusters, we used the Marsbar toolbox for SPM to extract significant clusters; then, we extracted voxel-by-voxel beta weights for these clusters from the beta_00*.img images corresponding to the effect of interest; and, finally, we calculated the average beta weight for the cluster.

To report the coordinates of the peak voxel of each cluster in the Montreal Neurological Institute (MNI) space (Table II), we coregistered statistical maps (in RAVENS space) into the MNI space by performing rotation with minimum transformation. The coregistration procedure was implemented using the SPM8 template T1 images according to the following transformation:

$$X1 = -1^{*}X - 0.022^{*}Y - 0.007^{*}Z + 223.112$$
$$Y1 = 0.022^{*}X - 0.999^{*}Y - 0.042^{*}Z + 236.230$$
$$Z1 = -0.006^{*}X - 0.042^{*}Y + 0.999^{*}Z - 4.037,$$

where *X*1, *Y*1, and *Z*1 are the transformed and *X*, *Y*, and *Z* the original coordinates.

To localize clusters anatomically and identify Brodmann areas we consulted the Talaraich Atlas [Lancaster et al., 2000] and the atlases embedded in MRIcron (Chris Rorden's MRIcron). To visualize results, we used MRIcron to overlay significant clusters on the average GM RAVENS image, which was calculated by SPM8 from the 87 subjects' unsmoothed RAVENS maps.

**TABLE I. Personality traits in the cohort**

| Domains | Time 1 mean and standard deviation | Time 2 mean and standard deviation | Intraclass correlation ($P < 0.001$) |
|---|---|---|---|
| Neuroticism | 46.38 (8.59) | 46.00 (8.54) | 0.85 |
| Extraversion | 48.38 (9.11) | 47.31 (8.54) | 0.90 |
| Openness | 50.75 (10.69) | 50.61 (10.79) | 0.91 |
| Agreeableness | 52.15 (7.55) | 53.02 (8.52) | 0.85 |
| Conscientiousness | 48.50 (8.16) | 48.53 (9.09) | 0.83 |

## RESULTS

### Neuropsychological Testing

Factor means and standard deviations are reported in Table I. We used a double-entry intraclass correlation to measure profile stability for all five factors across the 87 participants, obtaining an average intraclass correlation of 0.80. Means and standard deviations for select cognitive tests at the time of enrollment are reported in Table II.

### Neuroimaging

In the reported results, among other covariates, we are controlling for (years of) education. Similar results were obtained excluding education from the model.

**TABLE II. Neuropsychological testing results**

| Test score | Mean and standard deviation |
|---|---|
| MMSE | 28.8 (1.58) |
| CVLT-CA | 54.01 (10.50) |
| CVLT-long delay | 11.40 (3.38) |
| BVRT | 5.80 (3.75) |
| Card rotations | 78.06 (31.64) |
| Category fluency | 15.10 (2.84) |
| Letter fluency | 14.56 (4.24) |
| Trails A | 35.66 (12.85) |
| Trails B | 84.14 (35.58) |

Results are from the initial evaluation of the cohort (Time 1). MMSE, Mini Mental State Exam; CVLT, California Verbal Learning Test; BVRT, Benton Visual Retention Test; BVRT and Trails are reverse-keyed with higher scores indicating poorer performance.

**TABLE III. GM areas associated with personality**

| Contrast | Localization (neuroanatomical region and Brodmann's area) | Cluster size (voxels) | Peak-voxel *t*-statistic (*Z* value) | Significance level (after FWE-correction) | β Coefficient (GM RAVENS voxel value)/(NEO Factor *T*-score) | Peak-voxel(s) MNI coordinates |
|---|---|---|---|---|---|---|
| Positive linear correlation with N | (R) LG, BA 17 | 3604 | 4.78 | Cluster-level: $P < 0.001$ | 0.80 | 14, −66, and 2 |
| | (R) FG, BA 37/20 | 3131 | 4.40 | Cluster-level: $P < 0.001$ | 1.40 | 53, −58, and −24 |
| | (R) MOG, BA 18 | 439 | 4.38 | Cluster-level: $P = 0.035$ | 0.14 | 29, −98, and 1 |
| | (R) precentral gyrus, BA 4 | 1874 | 3.57 | Cluster-level: $P < 0.001$ | 1.90 | 36, −27, and 66 |
| | (R) CG, BA 18 | 700 | 3.51 | Cluster-level: $P = 0.002$ | 2.08 | 10, −82, and 16 |
| Negative linear correlation with *N* | (R) IOFG, BA 47 (lateral OFC) | 1036 | 5.23 | Cluster-level: $P < 0.001$ | −0.62 | 42, 38, and −23 |
| | (R) Rolandic opperculum, BA 22 | 3372 | 4.83 | Cluster-level: $P < 0.001$ | −0.75 | 70, −7, and 12 |
| | (R) MFG, BA 46 | 2863 | 4.55 | Cluster-level: $P < 0.001$ | −1.30 | 52, 46, and 15 |
| | (R) PHG, BA 28 | 898 | 4.27 | Cluster-level: $P < 0.001$ | −1.30 | 20, 2, and −30 |
| | (R) MTG, BA 21 | 1087 | 3.89 | Cluster-level: $P < 0.001$ | −2.06 | 59, 1, and −26 |
| Positive linear correlation with E | (L) STG, BA 22 extending into the (L) MTG, BA 21; ITG, BA20; PHG, BA 36 | 21,333 | 5.60 | Peak-level: $P = 0.008$; Cluster-level: $P < 0.001$ | 1.66 | −50, −8, and −7 |
| | (R) MFG, BA 44/46 | 6646 | 5.45 | Peak-level: $P = 0.018$; Cluster-level: $P < 0.001$ | 1.18 | 34, 22, 34 |
| | (L) aCG, BA 32 | 13,199 | 5.26 | Peak-level: $P = 0.044$; Cluster-level: $P < 0.001$ | 1.86 | −6, 42, and 15 |
| | (L) MFG, BA 46 | 7280 | 4.95 | Cluster-level: $P < 0.001$ | 1.72 | −26, 38, and 26 |
| | (L) SMA, BA 3 | 2171 | 4.44 | Cluster-level: $P < 0.001$ | 1.69 | −60, −20, and 42 |
| | (L) IOG, BA 19 | 622 | 4.36 | Cluster-level: $P = 0.004$ | 0.75 | −53, −74, and −7 |
| | (L) STG, BA 22 | 1029 | 3.95 | Cluster-level: $P < 0.001$ | 1.50 | −54, −26, and 6 |
| | (L) SFG, BA 6 | 736 | 3.80 | Cluster-level: $P = 0.001$ | 1.37 | −25, −8, and 60 |
| | (R) insula | 638 | 3.80 | Cluster-level: $P = 0.004$ | 1.48 | 38, 4, and 1 |
| Negative linear correlation with E | (R) PHG, BA 35 | 892 | 5.03 | Cluster-level: $P < 0.001$ | −0.51 | 24, −8, and −32 |
| | (L) IOG, BA 18 | 1914 | 5.02 | Cluster-level: $P < 0.001$ | −0.78 | −22, −101, and −12 |
| | (L) SPL, BA 7 | 652 | 4.04 | Cluster-level: $P = 0.003$ | −0.58 | −39, −63, and 58 |
| Positive linear correlation with O | (R) SFG, BA 10 (frontopolar cortex) | 5552 | 5.73 | Peak-level: $P = 0.004$; Cluster-level: $P < 0.001$ | 0.75 | 16, 64, and 22 |
| | (L) thalamus | 1172 | 3.59 | Cluster-level: $P < 0.001$ | 2.55 | −11, −14, and 17 |
| Negative linear correlation with O | (R) SOFG, BA 11 (medial OFC) | 2758 | 6.34 | Peak-level: $P < 0.001$; Cluster-level: $P < 0.001$ | −0.72 | 24, 33, and −13 |
| | (L) MFG, BA 47 | 655 | 5.64 | Peak-level: $P = 0.007$; Cluster-level: $P = 0.003$ | −0.16 | −54, 43, and −4 |
| | (R) FG, BA 36 | 4917 | 5.49 | Peak-level: $P = 0.014$; Cluster-level: $P < 0.001$ | −0.83 | 19, 8, and −44 |
| | (L) STG (fronto-insular cortex) | 3493 | 5.00 | Cluster-level: $P < 0.001$ | −1.88 | −41, −10, and −9 |
| | (R) SFG, BA 6 | 1535 | 4.88 | Cluster-level: $P < 0.001$ | −0.86 | 24, −5, and 70 |
| | (R) RG, BA 11 (medial OFC) | 4863 | 4.86 | Cluster-level: $P < 0.001$ | −1.41 | 8, 52, and −18 |

**TABLE III. (Continued)**

| Contrast | Localization (neuroanatomical region and Brodmann's area) | Cluster size (voxels) | Peak-voxel *t*-statistic (*Z* value) | Significance level (after FWE-correction) | β Coefficient (GM RAVENS voxel value)/(NEO Factor *T*-score) | Peak-voxel(s) MNI coordinates |
|---|---|---|---|---|---|---|
| | (L) postcentral gyrus, BA 5 | 3469 | 4.84 | Cluster-level: $P < 0.001$ | −0.65 | −20, −46, and 76 |
| | (R) precuneus, BA 7 | 1432 | 4.35 | Cluster-level: $P < 0.001$ | −1.12 | 3, −48, and 39 |
| | (L) FG, BA 20 | 895 | 4.08 | Cluster-level: $P < 0.001$ | −1.49 | −36, −17, and −36 |
| | (L) IPG, BA 40 | 1208 | 3.89 | Cluster-level: $P < 0.001$ | −1.59 | −48, −47, and 42 |
| | (L) SMA, BA 6 | 789 | 3.80 | Cluster-level: $P = 0.001$ | −1.17 | −3, 9, and 60 |
| Positive linear correlation with A | (R) IOFG, BA 47 (lateral OFC) | 1512 | 5.23 | Peak-level: $P = 0.050$; Cluster-level: $P < 0.001$ | 0.57 | 31, 33, and −25 |
| | (R) MOFG, BA 46 (lateral OFC) | 5476 | 4.59 | Cluster-level: $P < 0.001$ | 1.36 | 45, 56, and −2 |
| | (R) MTP, BA 20 | 1375 | 4.31 | Cluster-level: $P < 0.001$ | 1.63 | 46, 15, and −42 |
| | (L) SPG, BA 7 | 917 | 3.78 | Cluster-level: $P < 0.001$ | 1.08 | −17, −57, and 72 |
| Negative linear correlation with A | (B) SMFG, BA 8 | 12987 | 5.75 | Peak-level: $P = 0.004$; Cluster-level: $P < 0.001$ | −1.15 | −11, 36, 58 and 4, 40, and 53 |
| | (L) PHG, BA 28/36 | 2023 | 5.46 | Peak-level: $P = 0.017$; Cluster-level: $P < 0.001$ | −1.22 | −16, −7, and −28 |
| | (L) MFG, BA 46 | 1604 | 5.31 | Peak-level: $P = 0.035$; Cluster-level: $P < 0.001$ | −0.90 | −44, 54, and 18 |
| | (L) STG, BA 22 | 6105 | 5.26 | Peak-level: $P = 0.044$; Cluster-level: $P < 0.001$ | −2.25 | −55, −23, and 3 |
| | (L) SMFG, BA 32 | 698 | 4.05 | Cluster-level: $P = 0.002$ | −0.92 | −6, 31, and 36 |
| | (L) PHG, BA 37 | 992 | 3.90 | Cluster-level: $P < 0.001$ | −1.78 | −23, −36, and −6 |
| | (R) calcarine gyrus, BA 17 | 2003 | 3.75 | Cluster-level: $P < 0.001$ | −1.96 | 15, −57, and 10 |
| Positive linear correlation with C | (B) SFG, BA 8; (R) > (L) | 17801 | 6.42 | Peak-level: $P < 0.001$; Cluster-level: $P < 0.001$ | 1.30 | 9, 45, 54 and −9, 49, and 52 |
| | (R) postcentral gyrus, BA 3 | 4159 | 5.34 | Peak-level: $P = 0.031$; Cluster-level: $P < 0.001$ | 1.77 | 62, −13, and 44 |
| | (L) precuneus, BA 5 | 6715 | 5.24 | Peak-level: $P = 0.048$; Cluster-level: $P < 0.001$ | 1.79 | −13, −57, and 65 |
| | (R) precentral gyrus, BA 6 | 2003 | 5.23 | Peak-level: $P = 0.049$; Cluster-level: $P < 0.001$ | 0.87 | 38, −9, and 67 |
| | (L) FG, BA 19 | 1896 | 4.84 | Cluster-level: $P < 0.001$ | 1.76 | −41, −64, and −17 |
| | (L) caudate nucleus | 2814 | 4.67 | Cluster-level: $P < 0.001$ | 1.33 | −6, 7, and 13 |
| | (R) SFG, BA 8 | 3835 | 4.63 | Cluster-level: $P < 0.001$ | 1.46 | 30, 9, and 63 |
| | (L) SFG, BA 6 | 3646 | 4.61 | Cluster-level: $P < 0.001$ | 1.10 | −25, 3, and 71 |
| | (L) aCG, BA 32 | 2858 | 4.52 | Cluster-level: $P < 0.001$ | 1.51 | −10, 42, and 18 |
| | (R) STG, BA 22 and (R) IFG, pars opercularis, BA 44 | 5928 | 4.31 | Cluster-level: $P < 0.001$ | 1.96 | 59, −9, 10 and 56, 14, and 12 |
| | (L) LG, BA 18 | 797 | 3.88 | Cluster-level: $P = 0.001$ | 1.29 | −15, −64, and −8 |
| | (L) hippocampus | 1814 | 3.75 | Cluster-level: $P < 0.001$ | 1.56 | −22, −37, and 6 |
| Negative linear correlation with C | (R) MTP, BA 38 | 3560 | 6.11 | Peak-level: $P = 0.001$; Cluster-level: $P < 0.001$ | −0.21 | 20, 16, and −36 |

**TABLE III. (Continued)**

| Contrast | Localization (neuroanatomical region and Brodmann's area) | Cluster size (voxels) | Peak-voxel *t*-statistic (*Z* value) | Significance level (after FWE-correction) | β Coefficient (GM RAVENS voxel value)/(NEO Factor *T*-score) | Peak-voxel(s) MNI coordinates |
|---|---|---|---|---|---|---|
| | (L) STG, BA 21 | 736 | 5.46 | Peak-level: $P = 0.017$; Cluster-level: $P = 0.003$ | −0.26 | −64, −3, and 1 |
| | (B) SMFG, BA 10 (frontopolar cortex) | 14,345 | 5.28 | Peak-level: $P = 0.041$; Cluster-level: $P < 0.001$ | −0.37 | 12, 69, 10 and −7, 72, and 4 |
| | (L) SPL, BA 7 | 1782 | 5.18 | Cluster-level: $P < 0.001$ | −0.44 | −37, −66, 60 |
| | (L) CG, BA 17 | 4795 | 4.67 | Cluster-level: $P < 0.001$ | −0.54 | −2, −101, 11 |
| | (R) postcentral gyrus, BA 4 | 3843 | 4.61 | Cluster-level: $P < 0.001$ | −1.01 | 34, −34, 72 |
| | (R) IOFG, BA 11 (medial OFC) | 1289 | 4.26 | Cluster-level: $P < 0.001$ | −0.98 | 16, 39, −9 |

(R), right; (L), left; (B), bilateral; IFG, inferior frontal gyrus; MFG, middle frontal gyrus; SFG, superior frontal gyrus; SMFG, superior medial frontal gyrus; SMA, supplemental motor area; IOFG, inferior orbital frontal gyrus; MOFG, middle orbital frontal gyrus; SOFG, superior orbital frontal gyrus; RG, rectal gyrus; ITG, inferior temporal gyrus; MTG, middle temporal gyrus; STG, superior temporal gyrus; MTP, middle temporal pole; aCG, anterior cingulate gyrus; PHG, parahippocampal gyrus; IPG, inferior parietal gyrus; SPL, superior parietal lobule; SMG, supramarginal gyrus; LG, lingual gyrus; FG, Fusiform gyrus; CG, calcarine gyrus; MOG, middle occipital gyrus; IOG, inferior occipital gyrus; MNI, Montreal Neurological Institute; NS, nonsignificant (association).

### *Neuroticism*

*N* correlated positively with GM volume within: (R) lingual, BA 18; (R) fusiform, BA 37/20; (R) middle occipital and calcarine, BA 18, and (R) precentral, BA 4, cortices; and negatively with GM volume within: (R) orbitofrontal (OF; inferior orbital frontal gyrus, BA 47); (R) rolandic opperculum, BA 22; (R) dorsolateral PF (middle frontal gyrus, BA 46); (R) parahippocampal, BA 28; and (R) middle temporal, BA 21, cortices (Fig. 1 and Table III).

### *Extraversion*

E correlated positively with GM volume within: (L) temporal lobe (cluster extending from its peak at the superior temporal to the middle temporal, inferior temporal, and parahippocampal gyri); (L) dorsolateral PFC (clusters in BA 44, 46, and 6); (L) supplemental motor area, BA 3; (L) anterior cingulate (aCG), BA 32; (L) superior temporal gyrus, BA 22; and (R) insular cortices. E correlated negatively with GM volume within: (L) parahippocampal, BA 35; (L) inferior occipital, BA 18; and (L) superior parietal lobule, BA 7, cortices (Fig. 2 and Table III).

### *Openness*

O correlated positively with GM volume within (R) frontopolar (FP) cortex, BA 10, and (L) thalamus; and negatively with GM volume within OF, BA 11 and 47; bilateral FG, BA 36/20; (L) fronto-insular; (R) superior frontal and (L) supplemental motor area, BA 6; (L) post-central, BA 5; (R) precuneus, BA 7; and (L) inferior parietal, BA 40, cortices (Fig. 3 and Table III).

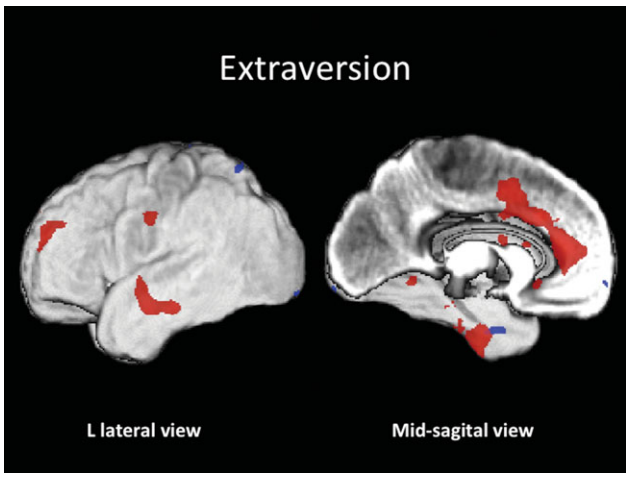


**Figure 2.**
Extraversion: Conjunction SPM T-map of positive (red) and negative (blue) correlations of E rendered on the subjects' average GM image ($z > 3.5$).

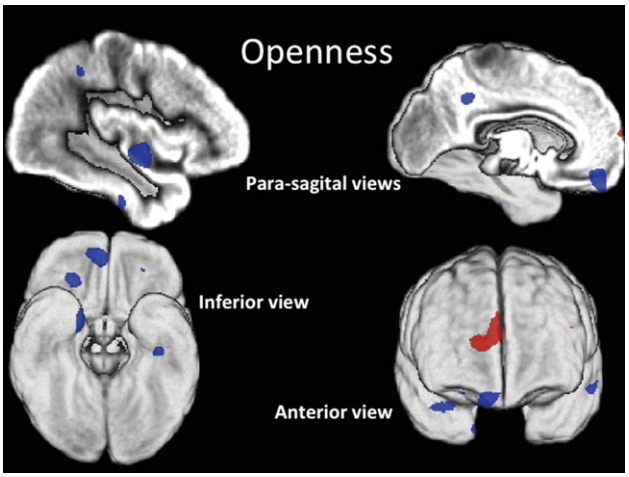


**Figure 3.**
Openness: Conjunction SPM T-map of positive (red) and negative (blue) correlations of O rendered on the subjects' average GM image ($z > 3.5$).

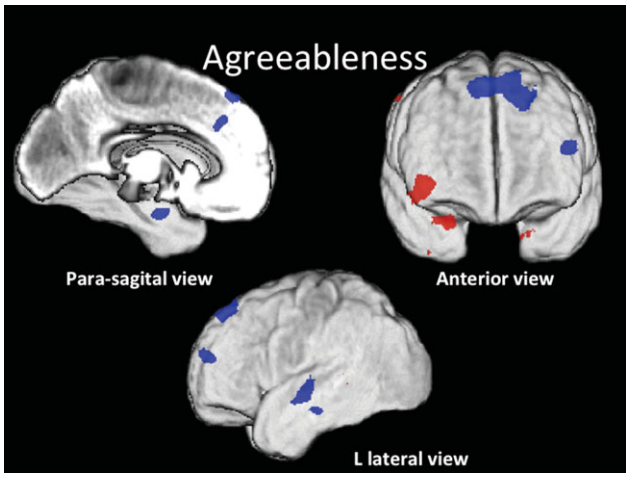


**Figure 4.**
Agreeableness: Conjunction SPM T-map of positive (red) and negative (blue) correlations of A rendered on the subjects' average GM image ($z > 3.5$).

### *Agreeableness*

A correlated positively with GM volume within: (R) lateral OF, BA 47/46; middle temporal pole, BA 20; and superior parietal, BA 7, cortices; and negatively with GM volume within bilateral dorsomedial PF (superior medial frontal gyrus, BA 8 and 32); (L) dorsolateral PF (middle frontal gyrus, BA 46); (L) parahippocampal gyrus, BA 36/37; (R) calcarine, BA 17; and (L) superior temporal gyrus, BA 22 (Wernicke's area), cortices (Fig. 4 and Table III).

### *Conscientiousness*

C correlated positively with GM volume within bilateral dorsomedial PFC (superior frontal gyrus, BA 8); (R) postcentral gyrus, BA 3; (L) precuneus, BA 5; (R) IFG, pars opercularis, BA 44; (R) superior temporal gyrus, BA 22; (R) precentral and (L) superior frontal gyri, BA 6; (L) aCG, BA 32; (L) caudate nucleus; (L) lingual gyrus; and (L) hippocampus; and negatively with GM volume within (R) middle temporal pole, BA 38; (L) superior temporal gyrus, BA 21; bilateral FP, BA 10; (L) superior parietal lobule, BA 7; (L) calcarine, BA 17; (R) postcentral gyrus, BA 4; and (R) medial OF, BA 11, cortices (Fig. 5 and Table III).

## DISCUSSION

We identified a number of GM regions associated with personality traits. This study focused on the GM, although there is evidence from a prior VBM study that there may also be WM volumetric differences associated with personality [DeYoung et al., 2010]. Given that, we are currently acquiring diffusion tensor imaging (DTI) sequences from the same cohort, which may reveal differences in the orientation, integrity, and relative strength of WM tracts, analysis of WM volume will be performed in combination with DTI in a future study. This study is exploratory and employed stringent statistical criteria. Methodological differences (such as our use of RAVENS maps methodology and the use of different statistical thresholds), as well as the much older age of our cohort, likely explain the different findings of our study and of a previous exploratory study of personality [DeYoung et al., 2010]. To increase confidence that reported associations reflect nonartifactual relations between brain structure and trait personality, we only report associations replicable across two time points surviving FWE-correction for multiple comparisons. Our

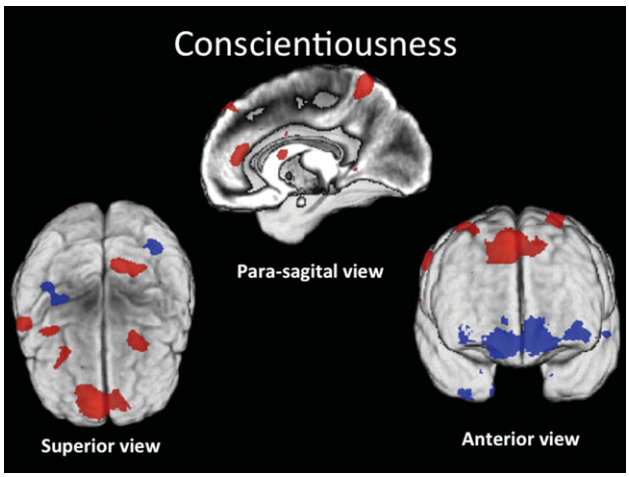


**Figure 5.**
Conscientiousness: Conjunction SPM T-map of positive (red) and negative (blue) correlations of C rendered on the subjects' average GM image ($z > 3.5$).

main goal has been to establish a set of reliable associations and motivate future hypothesis-driven research on the brain correlates of personality.

N reflects proneness to experience negative emotions [Canli, 2004; Haas et al., 2006a; McCrae and Costa, 2003]. In this study, higher N was associated with smaller (R) lateral OFC, in agreement with similar OFC findings in trait anxiety [Roppongi et al., 2010], anxiety disorder [van Tol et al., 2010] and depression [Lacerda et al., 2004]. Moreover, our observation of lower (R) dorsolateral PFC volume in relation to higher N may be related to the recent finding of decreased volume of this region in individuals at genetic risk for depression [Amico et al., 2010]. The positive association of N with ventral visual stream areas may reflect their engagement during emotional memory processing [Murty et al., 2010], which may be overactive in individuals with high N.

E, a trait reflecting proneness to experience positive emotions and engage in social interactions [Canli et al., 2001; Lucas and Diener, 2001; McCrae and Costa, 2003], was associated with larger cortical volume within (L) aCG, dorsolateral PFC and temporal regions. Regions of L PFC have been previously associated with E in a methodologically sound study in teenagers [Blankstein et al., 2009]. Left lateralized frontal activation has been observed in many positive emotion processing paradigms and has been related to E: individuals with high E show greater (L) aCG activation at rest [Johnson et al., 1999] and in response to positive emotional stimuli [Canli et al., 2004; Haas et al., 2006b], asymmetric (L) predominant frontal activation marks positive affect and approach tendencies [Davidson, 2004; Tomarken et al., 1992] and (L) dorsolateral PFC activation leads to suppression of sadness [Johnstone et al., 2007; Levesque et al., 2003; Ohira et al., 2006]. Our present findings suggest that chronic engagement of these frontal regions in individuals with high E may result in larger regional volumes or that pre-existing volumetric differences in these regions result in differential levels of E. In regards to pro-social aspects of E, the part of aCG associated with E is critical for decision making in social situations and for guiding social behavior [Behrens et al., 2009; Kennerley et al., 2006; Rushworth et al., 2007], while the (L) MTG (BA 21) is involved in emotion and intent-related Theory of Mind (ToM) [Calarge et al., 2003; Ethofer et al., 2006], both important aspects of social cognition.

Our findings in regards to N and E do not overlap with some of of the findings of Wright et al. [2006, 2007]. This may be due to the older age of our cohort (in regards to the findings of [Wright et al., 2006]) and a different analytical approach (such as the facts that we adjusted for total ICV and implemented a single linear model including all personality Factors). As a result, the strong associations we detected between certain regions reported by Wright et al. with other Factors [such as the association between (R) BA 6 and (L) BA 10 with C] may have rendered any weaker associations with N and E nonsignificant. Similarly, unlike previous studies [DeYoung et al., 2010; Omura et al., 2005; Rauch et al., 2005], we did not find any positive association between E and medial OFC, perhaps due to the much older age of our cohort (compared with [DeYoung et al., 2010]), the fact that we adjusted for total ICV, and the fact that, having included all personality Factors in the same GLM (unlike [Omura et al., 2005; Rauch et al., 2005]), we found two large (R) medial OFC clusters to be negatively associated with O.

In general, O was negatively associated with areas implicated in cautionary and inhibitory responses, including the (R) medial OFC, and (L) fronto-insular cortex, which responds to aversive physical [Jabbi et al., 2008; Wicker et al., 2003] and social stimuli [Kapogiannis et al., 2009; Sanfey, 2007] and fear of loss [Liu et al., 2007]. Moreover, Higher O was associated with larger frontopolar cortex, consistently with the prior finding of our team that frontopolar cortex resting-state regional cerebral blood flow positively correlates with O in both sexes [Sutin et al., 2009]. The FP cortex plays important roles in cognitive control by maintaining certain tasks in temporary suspension while other tasks are being executed [Koechlin and Hyafil, 2007] and is a key area for creativity [de Souza et al., 2010]; its enlargement in individuals with high O may enable them to hold alternative courses of action in working memory and experiment with new options and ideas.

A is primarily a dimension of interpersonal tendencies and its positive association with (R) OFC volume may relate to the region's key role in social and moral cognition [Behrens et al., 2009; Moll et al., 2005] and trust [Phan et al., 2010]. Our finding is also in agreement with the positive correlation of (R) OFC volume with A in Frontotemporal Dementia [Rankin et al., 2004] and with empathy in a range of neurodegenerative diseases [Rankin et al., 2006]. On the other hand, the increase in A with smaller bilateral dorsomedial PFC, BA 8, is in agreement with the finding of decreased other-critical sentiments associated with hypometabolism in this region in Frontotemporal Dementia patients [Moll et al., 2010].

Higher C was associated with enlargement of sensorimotor areas involved in motor planning (BA 3, 5, and 6), perhaps reflecting increased tendency for motor deliberation prior to execution. In particular, C was positively associated with rostral premotor cortex that is concerned with planning cognitively demanding tasks [Lindner et al., 2010; Picard and Strick, 2001], perhaps reflecting a tendency to think carefully before acting (C6 or Deliberation is a facet of C). In agreement with DeYoung et al. [2010], we found larger bilateral dorsomedial PFC, BA 8, in individuals with higher C, which we also interpret as a reflection of superior top down control on behavior based on rules and distant goals [DeYoung et al., 2010; du Boisgueheneuc et al., 2006; Rowe et al., 2000]. However, the compulsive tendencies, rigidity, and cognitive inflexibility associated with high C may be reflected by the finding of higher putamen and lower FP and OFC volumes [Fineberg et al., 2010].

## CONCLUSIONS

Our findings provide a comprehensive account of structural GM correlates of personality based on reliable associations across two time points. Given that this study is correlational, our findings do not indicate causality and various interpretations are viable. First, systematically differing experiences because of personality may alter cortical plasticity over time. Regional plastic changes have been demonstrated for a range of persistently practiced activities, including development of complex visuomotor and musical skills [Draganski et al., 2004; Erickson et al., 2010; Gaser and Schlaug, 2003], formation of hippocampus-mediated memories [Maguire et al., 2000, 2006] and enhancement of cognitive performance [Dickerson et al., 2008]. MRI-measured plastic changes in GM are presumably due to changes in neuronal number and size [Mechelli et al., 2005] and synaptic density [Kleim et al., 1996]. Second, early individual differences in brain development may lead to predispositions toward certain personality traits in adulthood [Schwartz et al., 2010] and complex abilities, such as creativity or musical skills [Gaser and Schlaug, 2003; Takeuchi et al., 2010]. Finally, persistent application of personality traits may amplify inherent trends in the regional pattern of GM. Future research on the neural basis of personality is needed to elucidate causality.

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