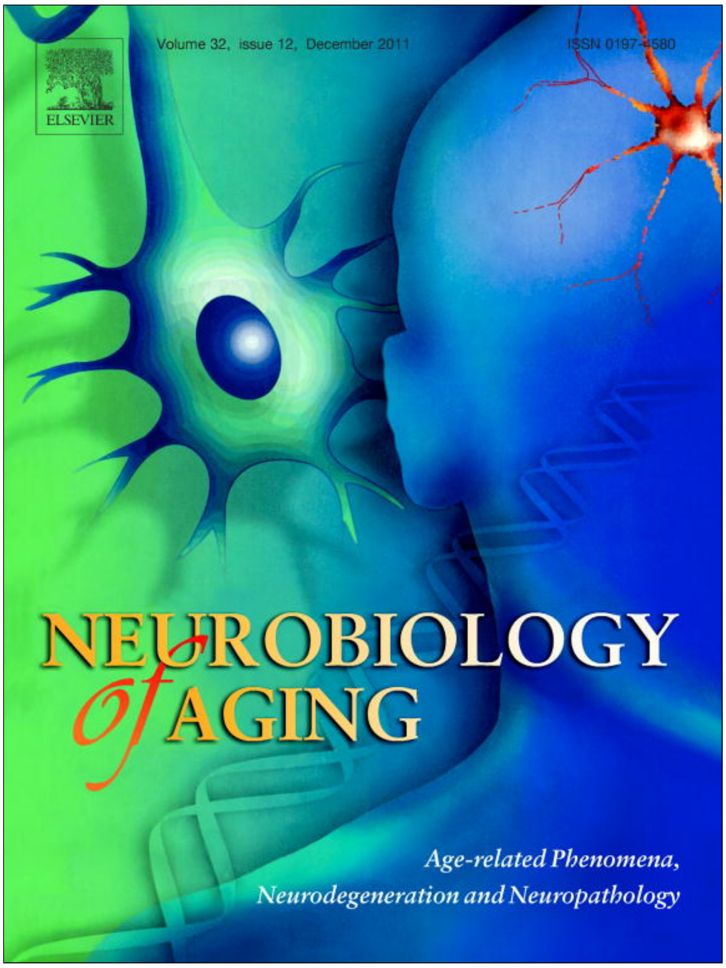
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Exploring the relationship between personality and regional brain volume in healthy aging

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Abstract

Aging is characterized by a reduction in regional brain volumes, particularly in prefrontal and medial temporal regions. Recent evidence suggests that personality may be related to neuroanatomical integrity. The present investigation explored whether the three targeted personality traits of neuroticism, conscientiousness, and extraversion moderated cross-sectional age-related decline in measures of neural integrity. Estimates of the personality traits and volumes of cerebral gray and white matter, prefrontal and medial temporal regions were obtained in a sample of 79 healthy adults aged 44–88. Higher neuroticism was associated with smaller regional volumes and greater decreases in volume with increasing age. Higher conscientiousness was related to larger regional volumes and less decline with advancing age. These results suggest that personality may not only relate to, but may also moderate age-related cross-sectional decline in prefrontal and medial temporal regions.

Keywords: Extraversion; Conscientiousness; Neuroticism; Atrophy; Volumetry; Prefrontal cortex; Hippocampus; Amygdala

1. Introduction

Changes in brain structure are an inherent component of the aging process. However, the extent of these structural changes varies across region with research indicating disproportionate declines in prefrontal regions and more modest changes in medial temporal regions (see Hedden and Gabrieli, 2004; Raz, 2004; Raz and Rodrigue, 2006 for reviews). Aging is also associated with a variety of cognitive deficits with executive control and memory processes subserved by prefrontal and medial temporal lobe regions particularly affected (see Balota et al., 2000; Hasher and Zacks, 1988, for reviews). Several factors have emerged that may moderate structural and functional declines in old age, including exercise (e.g., Bugg and Head, 2009; Colcombe et al., 2005), physiological factors (e.g., Erickson et al., 2008; MacLullich et al., 2005), and mental health (e.g., Gunning-Dixon et al., 2008; Yehuda et al., 2007).

The present paper explores the relationship between personality and the effects of age on brain structures. Personality refers to the long-term character, behavioral traits, and motivations of individuals. These tendencies are dispositional rather than absolute, apply to a broad number of contexts, and are relatively enduring (McCrae and Costa, 1984). Personality itself is a dimensionalized construct, often conceptualized within Costa and McCrae's Five-Factor Model (Costa and McCrae, 1992), which includes neuroticism, conscientiousness, extraversion, agreeableness, and openness.

Although one cannot make strong directional arguments from cross-sectional data, it is possible that personality may modulate the effects of age on brain structures. For example, in adolescents higher effortful control (similar to conscientiousness) has been associated with larger hippocampal and orbitofrontal volumes (Whittle et al., 2008). Negative associations between neuroticism and cerebral brain atrophy in young and middle-aged adults have also been observed (Knutson et al., 2001). At a regional level, neuroticism and

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extraversion are associated with prefrontal cortical thickness in both young and older adults (Wright et al., 2006, 2007). These associations suggest that personality may be a potential moderator of normative age effects on brain structure though this has not been directly examined.

There is also evidence demonstrating links between personality traits and pathological aging. For example, conscientiousness and neuroticism, as assessed with the NEO Personality Inventory (Costa and McCrae, 1992), can effectively discriminate between healthy and pathological aging on a level comparable to and independently of existing psychometric measures (Duchek et al., 2007). In longitudinal studies, higher levels of distress proneness (akin to neuroticism) and lower levels of conscientiousness have been associated with increased risk of Alzheimer's disease (AD; Wilson et al., 2003; Wilson et al., 2007a,b). Notably, neither conscientiousness nor distress proneness traits appear to be directly correlated with AD-related neuropathology or other AD risk factors in work by Wilson et al. (2003, 2007a,c), leading these authors to speculate about the possibility of other mechanisms whereby personality impacts neurobiology (e.g., Wilson et al., 2007a). Thus, the association between personality and AD may reflect an interaction of personality effects and normal, age-related processes rather than an effect specific to neurodegenerative disease.

The causal pathway may also reflect an influence on personality by changes or differences in brain morphology. For example, there is evidence of the influence of neurodegenerative processes on personality. A hallmark early symptom of frontotemporal dementia (FTD) is a change in personality (Neary et al., 1998), and different pathologies of FTD have been shown to precipitate different personality changes (Rankin et al., 2003). Regardless of direction of influence, the extant literature clearly demonstrates an important link between neuroanatomical integrity and personality in aging.

Critically, research also demonstrates potential mechanisms through which personality may influence brain structure and functioning. Animal models demonstrate that chronic stress, a frequent trait of neurotic individuals, has deleterious effects on neural integrity, particularly in subregions of the prefrontal cortex and in medial temporal lobe regions such as the hippocampus and amygdala (see Radley and Morrison, 2005; Sandi and Pinelo-Nava, 2007, for reviews). Specifically, prolonged stress induces dendritic atrophy in both the hippocampus and medial prefrontal cortex (Radley and Morrison, 2005), synaptic loss and suppression of neurogenesis in the hippocampus (Radley and Morrison, 2005) and alterations of limbic connectivity (Poeggel et al., 2003). Thus, chronic stress and aging may interact to increase susceptibility to structural and cognitive decline (see McEwen, 2002; Sapolsky, 1986, for reviews).

In contrast to neuroticism, the potential mechanisms for effects of conscientiousness and extraversion on structural integrity are less clear. Conscientiousness is negatively related to risky health behaviors and positively related to beneficial health-related behaviors, such as exercise and other lifestyle factors (see Bogg and Roberts, 2004; Rhodes and Smith, 2006, for reviews). These beneficial health-related behaviors may well serve to buttress against the effects of age. For example, aerobic exercise leads to larger prefrontal volumes and moderates age-related atrophy in medial temporal lobe regions (e.g., Bugg and Head, 2009; Colcombe et al., 2003, 2005). Extraversion is positively associated with physical activity (see Rhodes and Smith, 2006, for a review) and social engagement, a trait of extraversion (McCrae and Costa, 1984), is associated with the preservation of cognitive function in the elderly (Hertzog et al., 2009).

Considering the associations between personality and brain structure, the primary goal of the current investigation was to assess whether personality is related to the effects of age on specific brain regions observed in previous research (see Hedden and Gabrieli, 2004; Raz, 2004; Raz and Rodrigue, 2006, for reviews). Specifically, neuroticism, conscientiousness, and extraversion may have a moderating effect on cross-sectional age-related decline in brain volume in prefrontal and medial temporal regions. Highly neurotic individuals experience higher levels and more frequent occurrence of self-reported negative affect during everyday experiences (Griffin et al., 2006). This finding, coupled with observations of stress effects in prefrontal and medial temporal regions in animal work (see Radley and Morrison, 2005; Sandi and Pinelo-Nava, 2007, for reviews), suggests a relationship between high levels of neuroticism and age-related volumetric reductions in cortical and subcortical regions of interest. Because conscientiousness has been associated with reduced AD risk, reduced cognitive impairment, and larger hippocampal and orbitofrontal volumes (Duchek et al., 2007; Whittle et al., 2008; Wilson et al., 2007b), it was hypothesized that higher levels of this trait would be related to less age-related decline in these areas. Finally, extraversion is positively correlated with cortical thickness in prefrontal regions and is associated with more efficient processing in prefrontal regions (Gray and Braver, 2002; Wright et al., 2006, 2007); therefore, it was hypothesized that higher extraversion would be related to less age-related decline on cortical volumes.

2. Method

2.1. Participants

Eighty-three individuals were recruited from the Washington University Alzheimer's Disease Research Center. Exclusionary criteria included history of neurological disorders, stroke, head injury, hypertension, drug or alcohol abuse, and depression. Four individuals were excluded due to multiple outlier values, see Section 2.5 below. Thus, the final sample consisted of 79 individuals (59 females) aged 44–88 ($M = 66.0$; SD = 12.5). Participants were classified as nondemented (CDR = 0) according to the interview-based Clinical Dementia Rating scale (Berg, 1988), a validated measure that is effective in detecting the earliest stages of

Table 1
Demographic characteristics of the sample.

Variable	Mean (SD)
Age	65.7 (12.2)
Age skewness	−.05 (.3)
Age kurtosis	−1.4 (.5)
Gender (F/M)	59/20
Education (years)	15.6 (2.6)
Mini-mental status exam	29.3 (.9)
Socioeconomic status	2.2 (1.0)
Neuroticism	43.5 (9.6)
Conscientiousness	49.0 (11.0)
Extraversion	54.9 (10.7)

dementia (Morris, 1993). Socioeconomic status (SES) was obtained via the Hollingshead four-factor index of social position where one refers to high-privilege and 4 refers to low-privilege (Hollingshead, 1975). All participants also completed the Mini-Mental State Exam, a 30-item estimate of gross cognitive status. Participant demographic information is summarized in Table 1. Participant consent was obtained in accordance with the Washington University Human Research Protection Office.

2.2. Personality assessment

All participants completed the NEO Five-Factor Inventory, a shortened version of the NEO Personality Inventory-Revised questionnaire (NEO-PI-R; Costa and McCrae, 1992) that has been shown to be both reliable and consistent with the NEO-PI-R (Costa and McCrae, 1992). The questionnaire contains 60 items rated on a 5-point Likert scale ranging from "strongly disagree" to "strongly agree." The five factors (12 items per factor) are neuroticism, extraversion, openness, agreeableness, and conscientiousness. In accord with the hypotheses outlined in Section 1, only scores from the neuroticism, extraversion, and conscientiousness dimensions were used in analysis. The index of personality dimensions were the gender adjusted *T*-scores.

2.3. Image acquisition and processing

All imaging was performed using a Siemens 1.5 Tesla Vision scanner (Erlangen, Germany). Cushions and a thermoplastic mask were used during scanning to reduce head movement. A scout image (TR = 15 ms, TE = 6 ms, flip angle = 30°, 2.34 mm × 1.17 mm × 8 mm resolution) was acquired first in order to center the field of view on the brain. Two to 4 T1-weighted sagittal MP-RAGE (Mugler and Brookeman, 1991) scans (TR = 9.7 ms, TE = 4 ms, flip angle = 10°, TI = 20 ms, TD = 200 ms, 1 mm × 1 mm × 1.25 mm resolution) were acquired in each subject. Image processing steps have been described in detail in previous publications (Buckner et al., 2004; Fotenos et al., 2005; Head et al., 2005) and include inter- and intra-scan motion correction, atlas transformation, and averaging and inhomogeneity correction. Processing resulted in registered structural data resampled to 1 mm^3 voxels in the atlas space of Talairach and Tournoux (1988). Atlas normalization is equivalent to normalization based on intracranial volume and is minimally biased by global atrophy (Buckner et al., 2004).

2.4. Regional volumetry

Regional volume estimates were obtained using the Freesurfer image analysis suite, which implements an automated probabilistic labeling procedure (Desikan et al., 2006; Fischl et al., 2002, 2004). Each voxel in an MR image is assigned a neuroanatomical label based on probabilistic information from a manually labeled training set. This technique generates volumes with a high correspondence to manually generated volumes (Fischl et al., 2004). Regions of interest (ROIs) included cerebral gray matter, cerebral white matter, superior frontal gyrus, ventral/dorsal–lateral prefrontal cortex (VLPFC/DLPFC; combined middle and inferior frontal gyri), orbitofrontal cortex, parahippocampal gyrus (combined entorhinal cortex and parahippocampal gyrus), hippocampus, and amygdala.

2.5. Analytic approach

The data were first examined for univariate and multivariate outliers. To detect multivariate outliers in the sample, Mahalanobis D^2 (Lattin et al., 2003) was used, which identifies multivariate outliers in the sample by standardizing scores in a multidimensional space and measuring distance from the centroid (i.e., the multivariate mean). Each ROI served as a single variable and D^2 scores were computed for each participant. Four participants with unlikely D^2 values (beyond $p < .05$) were removed from analysis. These individuals had outliers across multiple regions, which suggest these data may have resulted from a software error in processing. An additional 8 participants had one data point far outside the normal range (i.e., greater than 3 SD). These values (representing 1% percent of the total data) were considered missing and replaced using regression imputation, which replaces the missing data point based on the values of all other variables (i.e., all personality and regional brain volume data).

To determine the necessity for inclusion of SES and education as covariates in the analyses, we first examined the zero-order correlations between these variables and the predictor variables (i.e., age and personality). Where these correlations were significant, the variables were included along with age in the regression models. We next performed a series of hierarchical linear regression analyses to assess our primary questions regarding the effects of age, personality, and the interaction of personality and age on the volumes of each ROI. All volumes were in atlas space, which is equivalent to adjustment for individual differences in body size using intracranial volume (Buckner et al., 2004). Age, any covariates and the personality factors were standardized, and the standardized variables were multiplied to create the interaction terms. In each regression model, standardized age was entered first (along with any necessary covariates), followed by the standardized personality variable, and then the interaction terms. In this way, a significant age × personality interaction term indicates moderation above and beyond the effects of either age or a given personality factor alone. Separate regression models were created for each personality dimension, and an alpha of .05 was set to indicate significance.

3. Results

3.1. Preliminary analyses

The distribution of age was found to be approximately uniform (Kolmogorov–Smirnov $Z = .610$, $p = .85$). Females were significantly younger than males (64 vs. 71, $t(77) = 2.33$, $p < .05$). There were no significant gender differences in conscientiousness, extraversion, education or SES (all $ps > .09$). Education was significantly correlated with age ($r(77) = -.24$, $p < .05$) and extraversion ($r(77) = .23$, $p < .05$), but not with conscientiousness or neuroticism ($ps > .13$); thus, education was included as a covariate in all models. There were no significant relationships between SES and the predictor variables (all $ps > .12$). In accord with standard practice, non-significant interactions involving education were dropped from the models and only significant interactions are specified in the relevant sections below.

3.2. Cerebral gray and white matter volumes

Age and education accounted for a significant amount of variance in cerebral gray volume ($\Delta R^2 = .61$, $F(2, 76) = 58.82$, $p < .001$; age $\beta = -.78$, $p < .001$; education $\beta = .01$, $p = .91$) and cerebral white matter volume ($\Delta R^2 = .60$, $F(2, 76) = 57.37$, $p < .001$; age $\beta = -.76$, $p < .001$; education $\beta = .06$, $p = .41$). Neuroticism accounted for a significant amount of variance in cerebral gray matter volume (Fig. 1A; $\Delta R^2 = .03$, $F(1, 75) = 6.67$, $p < .05$) such that individuals with higher neuroticism had smaller volumes. The age × neuroticism interaction was not significant ($F < 1$). In the analysis of cerebral white matter volume, the main effect of neuroticism was not significant ($F < 1$), but there was a significant age × neuroticism interaction ($\Delta R^2 = .04$, $F(1, 74) = 7.82$, $p < .01$). The cross-sectional decline with age was greater in individuals with higher neuroticism compared with those with lower neuroticism (see Fig. 2A).

There was a non-significant trend for a main effect of conscientiousness in the analysis of cerebral gray matter volume ($\Delta R^2 = .02$, $F(1, 75) = 3.49$, $p = .066$), indicating a trend for individuals higher in conscientiousness to have larger volumes. The age × conscientiousness interaction was not significant ($\Delta R^2 = .01$, $F(1, 74) = 2.03$, $p = .16$), but there was a significant three-way interaction of conscientiousness, age, and education ($\Delta R^2 = .02$, $F(1, 71) = 4.57$, $p < .05$). For individuals lower in education (based on a median split of

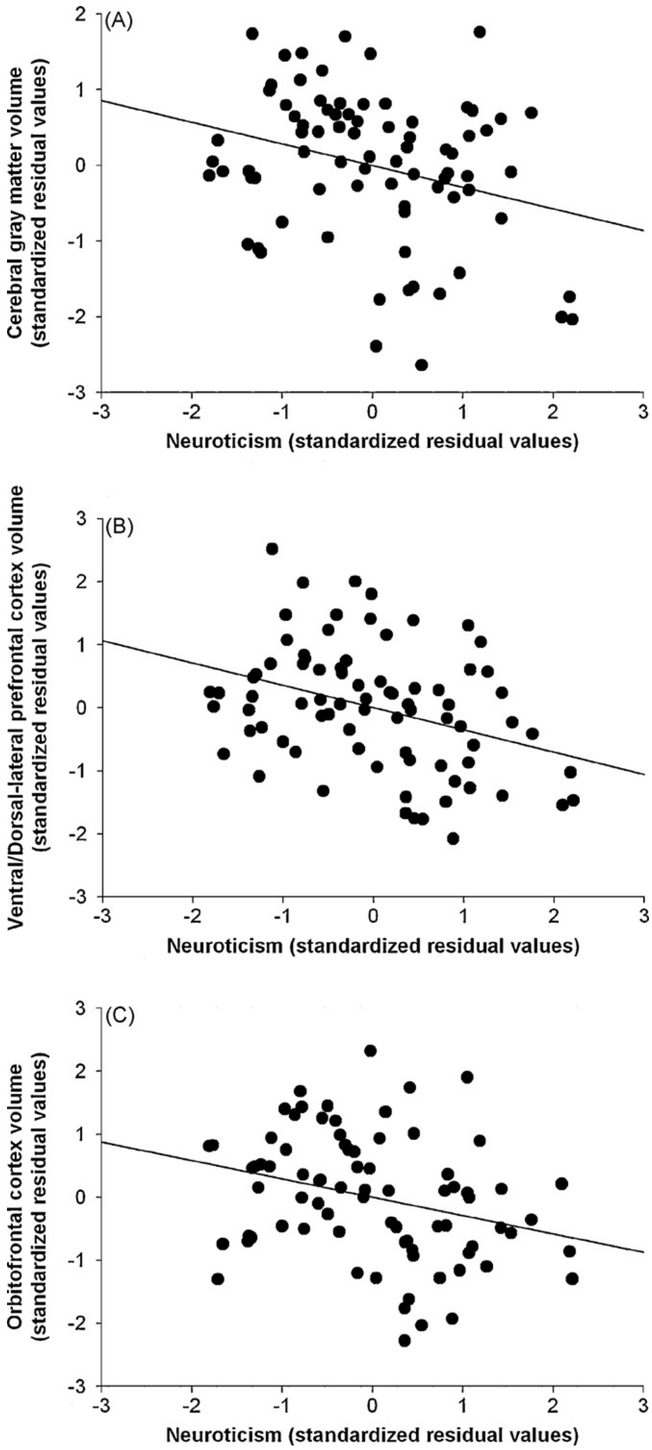

Fig. 1. Effects of neuroticism on global and regional atrophy. (A) Cerebral gray matter, (B) VLPFC/DLPFC, and (C) orbitofrontal cortex. Data are standardized residuals controlling for age and education.

the education variable), there was a significant effect of conscientiousness ($\Delta R^2 = .05$, $F(1, 31) = 4.92$, $p < .05$) and a non-significant age × personality interaction ($\Delta R^2 = .03$, $F(1, 30) = 3.02$, $p = .09$) such that those lower in conscientiousness tended to experience greater decreases in cerebral gray matter volume with cross-sectional age. Neither the

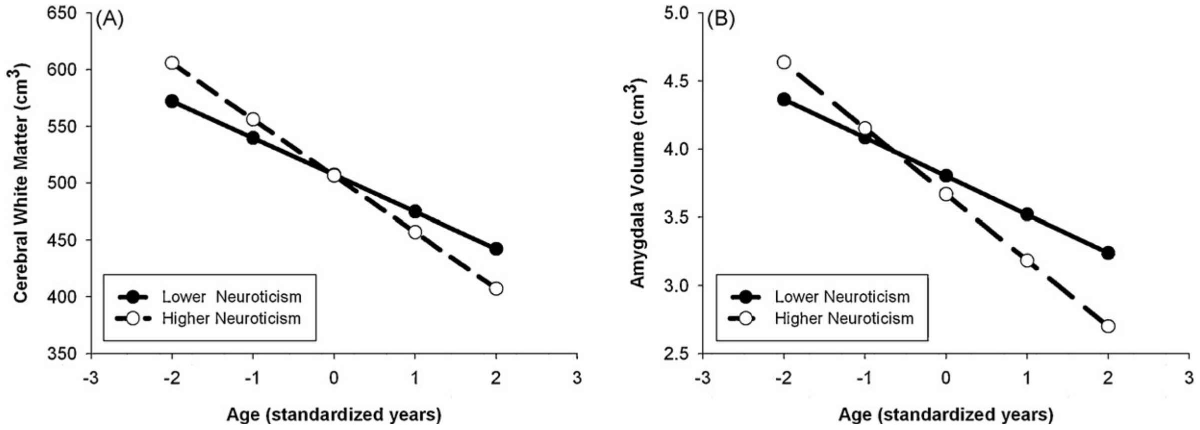

Fig. 2. Moderation of age effects by neuroticism. (A) Cerebral white matter and (B) amygdala. Plots based on data points estimated using the simple regression equation and represent the age × neuroticism interaction controlling for main effects of age, neuroticism and education (see text for details of regression analysis).

effect of conscientiousness nor the age × conscientiousness interaction was significant for individuals higher in education ($F < 1$). In the analysis of cerebral white matter volume, the main effect of conscientiousness was not significant, ($F < 1$), but there was a significant age × conscientiousness interaction ($\Delta R^2 = .07$, $F(1, 74) = 14.40$, $p < .001$). Specifically, higher conscientiousness was associated with smaller declines with age in comparison with lower conscientiousness (see Fig. 4A).

For cerebral gray matter volume neither the main effect of extraversion nor its interaction with age was significant (Fs < 1). In the cerebral white matter analysis, the main effect of extraversion was not significant ($F < 1$), but there was a non-significant trend for an age × extraversion interaction ($\Delta R^2 = .02$, $F(1, 74) = 2.89$, $p = .09$). This trend was subsumed under a significant three-way interaction of age, extraversion, and education ($\Delta R^2 = .03$, $F(1, 71) = 4.57$, $p < .05$). This interaction indicated a significant age × personality interaction in individuals with higher education, i.e., higher levels of extraversion were associated with a lower rate of cross-sectional decline with age ($\Delta R^2 = .07$, $F(1, 39) = 8.72$, $p < .01$). In individuals with lower education, there was not a significant age × extraversion interaction ($F < 1.05$).

3.3. Regional cortical volumes

Age and education accounted for a significant amount of variance in VLPFC/DLPFC ($\Delta R^2 = .51$, $F(2, 76) = 40.25$, $p < .001$; age $\beta = -.68$, $p < .001$; education $\beta = .12$, $p = .15$), superior frontal gyrus ($\Delta R^2 = .31$, $F(2, 76) = 17.32$, $p < .001$; age $\beta = -.57$, $p < .001$; education $\beta = -.06$, $p = .57$), and orbitofrontal cortex ($\Delta R^2 = .25$, $F(2, 76) = 12.48$, $p < .001$; age $\beta = -.48$, $p < .001$; education $\beta = .06$, $p = .58$). No main effects or interactions involving personality were significant in the superior frontal gyrus (all Fs < 1.08).

There were main effects of neuroticism in the analysis of VLPFC/DLPFC ($\Delta R^2 = .06$, $F(1, 75) = 10.73$, $p < .01$) and the orbitofrontal cortex ($\Delta R^2 = .06$, $F(1, 75) = 6.89$, $p < .05$). Higher scores on neuroticism were associated with smaller volume in both regions (see Fig. 1B and C, respectively). There was also a significant main effect of conscientious-

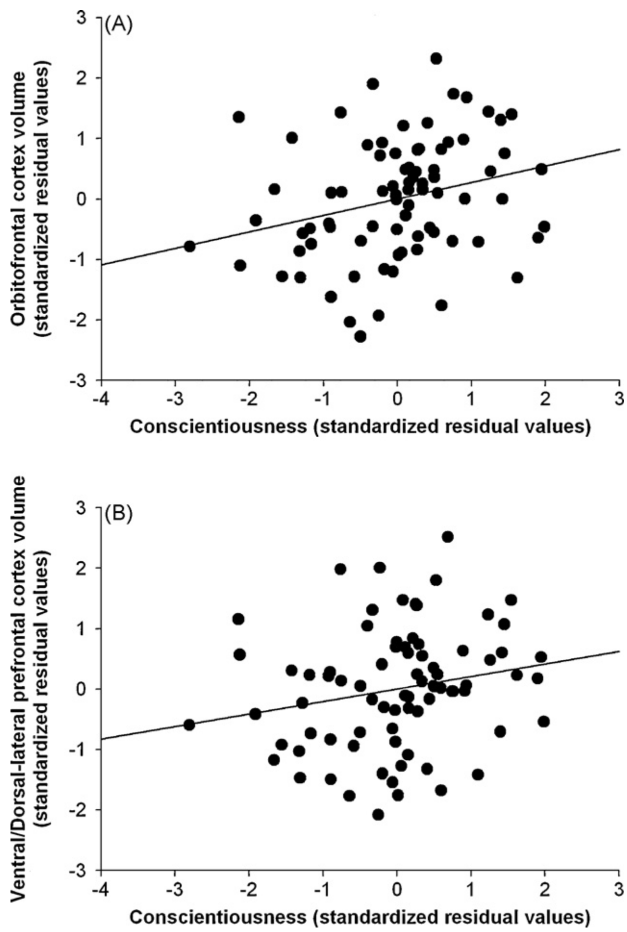

Fig. 3. Effects of conscientiousness on regional atrophy. (A) orbitofrontal cortex and (B) VLPFC/DLPFC. Data are standardized residuals controlling for age and education.

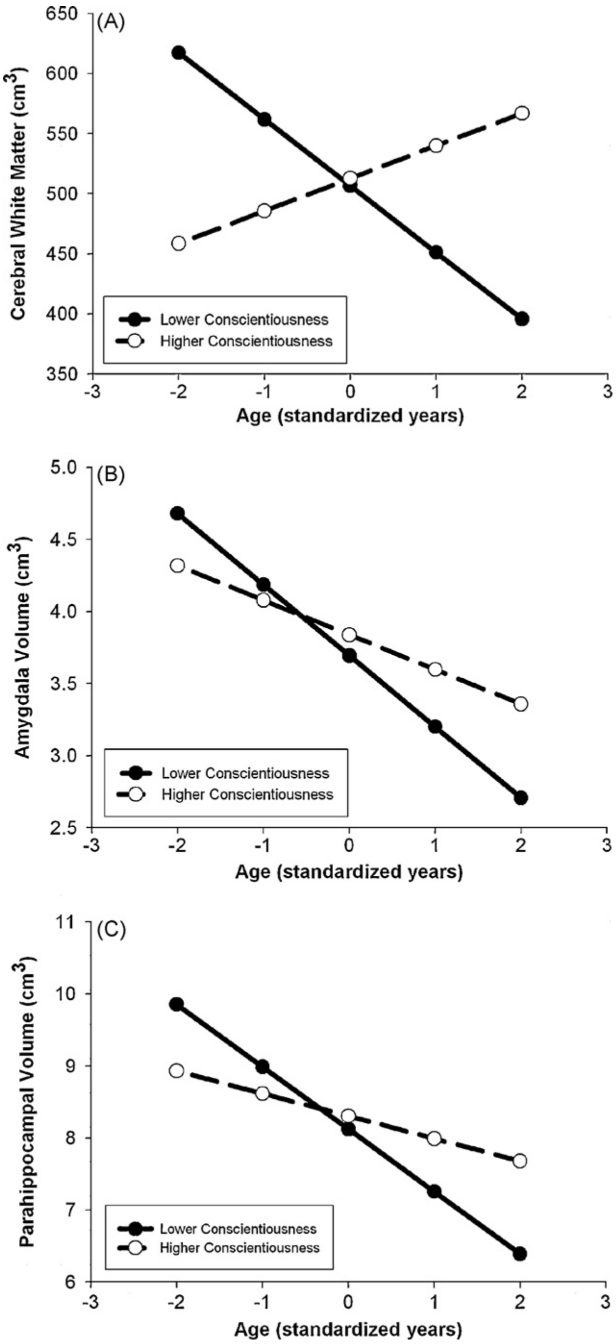

Fig. 4. Moderation of age effects by conscientiousness. (A) Cerebral white matter, (B) amygdala, and (C) parahippocampal gyrus. Plots based on data points estimated using the simple regression equation and represent the significant age × conscientiousness interaction controlling for main effects of age, conscientiousness and education (see text for details of regression analysis.

ness in the analysis of orbitofrontal cortex ($\Delta R^2 = .06$, $F(1, 75) = 5.99$, $p < .05$), and a non-significant trend for an effect of conscientiousness in VLPFC/DLPFC ($\Delta R^2 = .02$, $F(1, 75) = 3.35$, $p = .077$). Higher conscientiousness was associated with larger volumes in both regions as illustrated in Fig. 3. There were no significant age × personality interactions in either the orbitofrontal cortex or VLPFC/DLPFC (Fs < 1). There were no main effects or interactions involving extraversion for any of the regional cortical volumes (all Fs < 1.15).

3.4. Regional subcortical volumes

Age and education accounted for significant amount of variance for the hippocampus ($\Delta R^2 = .52$, $F(2, 76) = 41.52$, $p < .001$; age $\beta = -.734$, $p < .001$; education $\beta = -.06$, $p = .49$), amygdala ($\Delta R^2 = .41$, $F(1, 75) = 26.74$, $p < .001$; age $\beta = -.64$, $p < .001$; education $\beta = .02$, $p = .83$), and the parahippocampal gyrus ($\Delta R^2 = .26$, $F(1, 74) = 13.16$, $p < .001$; age $\beta = -.49$, $p < .001$; education $\beta = .07$, $p = .53$).

Neuroticism was not associated with volume in the hippocampus ($\Delta R^2 = .02$, $F(2, 75) = 2.44$, $p = .12$.), the amygdala ($F < 1$), or the parahippocampal gyrus ($F < 1$). The age × neuroticism interaction was not significant for the hippocampus or for the parahippocampal gyrus (Fs < 1). There was a non-significant trend for an age × neuroticism interaction for the amygdala ($\Delta R^2 = .02$, $F(1, 74) = 3.23$, $p = .077$) reflecting a trend for the decline with age in amygdala volume to be greater for individuals higher in neuroticism than for those with lower scores (see Fig. 2B).

Conscientiousness was not associated with volume in the hippocampus ($\Delta R^2 = .02$, $F(1, 54) = 2.56$, $p = .11$), the parahippocampus ($F < 1$) or amygdala ($F < 1$). There were significant interactions between conscientiousness and age for both amygdalar volume ($\Delta R^2 = .05$, $F(1, 74) = 6.42$, $p < .05$) and parahippocampal volume ($\Delta R^2 = .05$, $F(1, 74) = 5.64$, $p < .05$). Individuals with higher conscientiousness evidenced smaller cross-sectional age declines in amygdala and parahippocampal volume compared to those lower in conscientiousness (see Fig. 4B and C, respectively). The age × conscientiousness interaction was not significant for the hippocampus ($\Delta R^2 = .01$, $F(1, 75) = 1.31$, $p = .26$). Neither extraversion nor its interaction with age was related to volume in any of the subcortical ROIs (all Fs < 1).

4. Discussion

The extant literature has established deleterious effects of aging on regional brain structures and evidence regarding potential moderators of these age effects are emerging (e.g., Bugg and Head, 2009; Colcombe et al., 2005; Gunning-Dixon et al., 2008; MacLullich et al., 2005). The personality traits of neuroticism, conscientiousness and extraversion have each been associated with neuroanatomical integrity (e.g., Knutson et al., 2001; Whittle et al., 2008; Wright et al., 2006, 2007). The present investigation examined the relationship between personality and cerebral and regional structural integrity, both directly and as a potential moderator of cross-sectional age-related decline, while controlling for overall age-related effects and education. Overall, we replicated the finding that personality is associated with regional volumes in middle-aged and older adults and extended this work to demonstrate that a relationship between personality and age-related decline can be obtained in a cross-sectional study.

The most consistent observations of interactive effects of age and personality were for cerebral white matter volume. Cerebral white matter volume reflects the integrity of the connectivity of brain systems and there is extensive evidence of age effects on white matter (see Gunning-Dixon et al., 2009; Raz and Rodrigue, 2006, for reviews). These age effects also appear to contribute to disruptions in functional connectivity (Andrews-Hanna et al., 2007). This evidence in conjunction with current data supports the argument that the examination of interconnected networks may be more relevant than focusing on specific regions in understanding age effects (Tisserand and Jolles, 2003).

4.1. Effects of neuroticism

Existing evidence suggests that neuroticism or stress is associated with negative outcomes (Duchek et al., 2007; Knutson et al., 2001; Radley and Morrison, 2005; Wilson et al., 2003). Consistent with this literature, higher levels of neuroticism were associated with smaller volumes in cerebral gray matter, VLPFC/DLPFC and orbitofrontal cortex. Neuroticism also interacted with age effects in cerebral white matter with a larger volumetric decrease with age for individuals higher in neuroticism. There was a similar, albeit non-significant, trend for amygdalar volume. Collectively, these results are consistent with the conceptualization that stress may increase susceptibility to structural decline (McEwen, 2002; Radley and Morrison, 2005; Sapolsky, 1986).

Considering the strong link between stress and alterations in the hippocampus (Kang et al., 2007; Poeggel et al., 2003; Radley and Morrison, 2005), neuroticism was expected to be associated with hippocampal volume. However, neuroticism neither directly affected the hippocampus nor functioned as a moderator of age-related decline. There are several possible reasons for this lack of effect. Neuroticism may be too broad a construct and effects attributable to neuroticism may be better captured by certain subfactors within the neuroticism dimension rather than the global estimate. For example, subfactors within neuroticism such as Anxiety or Vulnerability to Stress may more closely align with the experiential effects that contribute to negative effects in the hippocampus in non-human animals (Radley and Morrison, 2005). In addition, research indicates that the effect of stress on hippocampal integrity may occur in several ways, such as suppression of neurogenesis that may be difficult to detect in a volumetric analysis (Radley and Morrison, 2005).

4.2. Effects of conscientiousness

We also observed significant associations between the personality trait of conscientiousness and brain structure. Higher levels of conscientiousness were associated with larger orbitofrontal volumes, with similar non-significant trends in cerebral gray matter and VLPFC/DLPFC, which replicates and extends previous work (Radley and Morrison, 2005; Sandi and Pinelo-Nava, 2007; Whittle et al., 2008; Wright et al., 2007). In addition, individuals low in conscientiousness evidenced greater decreases with age in cerebral white matter, amygdala, and parahippocampal volumes. The specific mechanisms of the positive relationships with conscientiousness remain unclear and may include indirect mechanisms. Conscientious individuals tend to be self-disciplined and proactive (Costa and McCrae, 1992), and as a result, they may be more likely to engage in beneficial health-related activities, such as physical activity (see Bogg and Roberts, 2004, for a review), which has been linked to increased volume in prefrontal regions (e.g., Colcombe et al., 2006). Interactive effects (i.e., moderation) of age and exercise have been observed in the medial temporal lobe consistent with the interactive effects of age and conscientiousness observed in parahippocampal and amygdalar regions (Bugg and Head, 2009).

4.3. Effects of extraversion

Finally, extraversion was only associated with a non-significant trend for an interactive effect with age in cerebral white matter. While prior research has found positive associations between extraversion and lateralized prefrontal and amygdalar integrity (Omura et al., 2005; Rauch et al., 2005; Wright et al., 2006, 2007), the present study was not able to investigate lateralized effects of personality and age on brain volume due to sample size restrictions. Effects of extraversion may be expressed in other indices of structural integrity, such as cortical thickness or amygdalar gray matter concentration assessed in previous work (Omura et al., 2005; Wright et al., 2007). The mechanisms underlying the interactive trend of extraversion and age are unclear, but may reflect indirect effects whereby extraverts engage in higher levels of physical activity (Rhodes and Smith, 2006) and social engagement (McCrae and Costa, 1984), which in turn may lead to enhanced neural and cognitive outcomes (Bugg and Head, 2009; Hertzog et al., 2009).

4.4. Limitations

Although the present study was motivated by literature suggesting a moderating effect of personality on age-related decline, it is important to note that our data do not exclude the possibility that changes in brain structure induce personality differences. The present study cannot distinguish between these two alternatives in a compelling way, but serves to emphasize the important relationship between personality and volume in key brain regions in aging. Furthermore, the present study is also limited by its cross-sectional design and observed effects may not generalize beyond the age ranges included. A more convincing method to demonstrate personality effects would require a longitudinal study across a broader range of ages and we are currently engaged in such a study.

There were also two unexpected interactive effects with age, personality and education. Conscientiousness interacted with age and education in cerebral gray matter and extraversion interacted with age and education cerebral white matter. A post hoc explanation of the interactions with education may suggest protective effects involving cognitive reserve (Stern, 2009). However, understanding the role of education requires targeted examination in future investigations with larger samples.

4.5. Future directions and conclusions

It is possible that the personality-related effects reported here may ultimately play a role in age-related cognitive declines. Personality traits akin to neuroticism and extraversion have been linked neural processing efficiency in prefrontal regions (Gray and Braver, 2002; Gray et al., 2005), and the interactive effects of personality with age in the amygdala and parahippocampus may be tied to their roles in emotion and memory processing, respectively. There is evidence for a link between neuroticism and cognitive outcomes (Pearman and Storandt, 2004; Robinson and Tamir, 2005) and these changes may be moderated or even mediated by volumetric changes.

An intriguing extension of the present findings would examine whether the observed associations between age and personality are maintained or violated in individuals with the earliest stages of Alzheimer's disease (AD). Research indicates that changes in personality are an early sign of progression to demented status (Balsis et al., 2005) and personality may be a risk factor for developing AD (Duchek et al., 2007; Wilson et al., 2003, 2007a,b,c). While the present results demonstrate that personality may not only influence, but perhaps moderate age-related decline in critical neuroanatomical regions, future work should replicate and extend these findings to other components of pathological and non-pathological aging.

Conflict of interest

The authors and their institution have no conflicts of interest related to this work.

Disclosure statement

The data contained in this manuscript have not previously been published, nor has the manuscript been submitted elsewhere, nor will it be submitted elsewhere while under review. Appropriate ethical guidelines were followed with regard to the treatment of human subjects. Participant consent was obtained in accordance with the Washington University Human Research Protection Office. All authors have reviewed the manuscript and approve of its contents and validate the accuracy of the data.

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