Personality traits share overlapping neuroanatomical correlates with internalizing and
externalizing psychopathology

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Abstract

Although personality traits have been linked to internalizing and externalizing psychopathology, the extent to which these traits and psychopathological phenotypes share a common neuroanatomical structure is unclear. To address this gap, we used structural neuroimaging and self-report data from 1101 participants in the Human Connectome Project to generate neuroanatomical profiles (NAPs) of FFM traits and psychopathology indices composed of the thickness, surface area, and gray matter volume of each region in the Desikan atlas, then used a profile matching approach to compare the absolute similarity of the FFM trait NAPs and psychopathology index NAPs. These analyses indicated that the NAPs derived from Neuroticism and Extraversion demonstrated medium to large positive and negative absolute similarities to the NAPs of internalizing psychopathology, respectively. Similarly, the NAPs of Agreeableness and Conscientiousness showed medium to large negative relations with the NAPs of antisocial behavior and substance use, respectively. These results suggest that similar neuroanatomical correlates underlie specific personality traits and symptoms of psychopathology, providing support for dimensional models that incorporate personality traits into the etiology and manifestation of psychopathology.

Keywords: Five Factor Model; personality; psychopathology; neuroanatomy; Human Connectome Project

General Scientific Summary: This study investigated the extent to which personality traits and symptoms of psychopathology share common neuroanatomical structures. Results highlight the importance of considering personality in dimensional models of psychopathology.

Personality traits share overlapping neuroanatomical correlates with internalizing and externalizing psychopathology

Personality traits – characteristic patterns of thinking, feeling, and behaving – have proven to be highly useful constructs for understanding human functioning, demonstrating meaningful relations with a host of outcomes related to health (Booth-Kewley & Vickers, 1994), academic performance (Poropat, 2009), job performance and satisfaction (Chiaburu, Oh, Berry, Li, & Gardner, 2011; Judge, Heller, & Mount, 2002), relational functioning (Malouff, Thorsteinsson, Schutte, Bhullar, & Rooke, 2010), crime and antisocial behavior (e.g., Jones, Miller, & Lynam, 2011), and life satisfaction (DeNeve & Cooper, 1998). Much of this work has used the Five Factor Model/Big Five (FFM)¹ of personality to assess and organize these relations. Although the designations vary slightly by measure, the five core FFM traits are often referred to as Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness.

The FFM has contributed substantially to the contemporary understanding of psychopathology, particularly the higher-order internalizing and externalizing factors (e.g., Achenbach, 1966; Krueger, Caspi, Moffitt, & Silva, 1998). For instance, a meta-analytic review suggests that (high) Neuroticism, (low) Extraversion, and (low) Conscientiousness are characteristic of individuals with anxiety and depressive disorders (Kotov, Gamez, Schmidt, & Watson, 2010). Although there were mild trait-based differences between diagnoses, the anxiety (e.g., generalized anxiety disorder; panic disorder) and depressive (e.g., major depressive disorder; dysthymic disorder) disorders showed remarkably similar personality profiles, which is

¹Due to the overlap between the FFM and the Big Five, we use FFM to refer to this common organization.

consistent with research suggesting the presence of a higher-order latent internalizing factor that characterizes internalizing psychopathology (Kotov et al., 2017; Krueger, 1999).

Similarly, multiple meta-analyses have demonstrated that (low) Agreeableness (i.e., Antagonism) and (low) Conscientiousness (i.e., Disinhibition) are robust correlates of antisocial behavior, including aggression, criminal behavior, and substance use (Jones et al., 2011; Kotov et al., 2010; Miller & Lynam, 2001), and predict antisocial-related outcomes across the lifespan (e.g., Henry, Caspi, Moffitt, & Silva, 1996). Of note, the Angry/hostility facet of Neuroticism is also linked to antisociality, but this trait is often considered “interstitial” and to be important in conceptualizing Neuroticism and (low) Agreeableness (e.g., John, Naumann, & Soto, 2008; see also APA, 2013). These traits have also been linked to laboratory aggression (e.g., Hyatt, Weiss, Carter, Zeichner, & Miller, in press) and criminal recidivism (Van Dam, Janssens, & De Bruyn, 2005) and are integral to conceptualizing higher-order latent externalizing factors of psychopathology, which include diagnoses such as antisocial personality disorder, conduct disorder, and substance use disorders (e.g., Kotov et al., 2017; Ruiz, Pincus, & Schinka, 2008). In fact, in the Hierarchical Taxonomy of Psychopathology (HiTOP), a recently developed, quantitative nosology (Kotov et al., 2017) that is a dimensional alternative to categorical models (e.g., DSM-5), maladaptive personality traits are posited to be related to all manifestations of psychopathology. Under the HiTOP model, personality traits are thought to be related to the various spectra of psychopathology (e.g., internalizing, externalizing), and to differentially underlie many of the clinical symptoms important in assessing psychological functioning. For example, trait Antagonism (i.e., low FFM Agreeableness) and trait Disinhibition (i.e., low FFM Conscientiousness) are both associated with symptoms of disorders such as Antisocial Personality Disorder, but are uniquely associated to Narcissistic Personality Disorder and

Substance Use Disorders, respectively (Kotov et al., 2010; Kotov et al., 2017; Malouff, Thorsteinsson, & Schutte, 2006). This is in line with research suggesting that personality disorders and other psychiatric diagnoses load onto the same general factors of psychopathology consistent with the HiTOP model (Kotov et al., 2011; Røysamb et al. 2011; Wright & Simms, 2015).

Despite the established links between personality and psychopathology, their relation is an active area of interest and disagreement in the psychological literature. For example, while many researchers have proposed that personality disorders can be captured and understood through the lens of the general personality traits (e.g., Miller et al., 2008; Widiger & Trull, 2007), others are skeptical of the validity and clinical utility of such approaches (e.g., Gunderson, 2010). As another prominent demonstration of this tension, the American Psychiatric Association only recently discarded the split between Axis I (the preponderance of psychological diagnostic categories) vs. Axis II disorders (personality disorders and intellectual disability; APA, 2013). This binary distinction was often taken to imply that personality traits are unique from or exist in a different sphere from other forms of psychopathology, an assumption which did not have strong empirical grounding.

Alternate models (e.g., Bagby et al., 2014; Kotov et al., 2017) propose that the same underpinnings that underlie individual trait differences (e.g., physiological, cognitive) are essential to understanding the differential manifestation of psychiatric disorders. For example, from the perspective of the Cybernetic Big Five Theory (CB5T; DeYoung, 2015), psychopathology involves dysfunction within an organized system (i.e., an individual) that results in the inability to attain goals identified by the system. If personality traits are conceived as individual differences in patterns of emotions, motivations, cognitions, and behaviors that

serve particular goal-related functions (e.g., dominance, social affiliation, avoidance), it naturally follows that the same mechanisms that characterize one's general tendencies toward certain states are relevant to understanding dysfunction that occurs within the system. For example, consider Extraversion, which is theoretically linked to heightened reward sensitivity processes (Allen & DeYoung, 2017; Gray, 1970). If person is especially low in trait Extraversion, the same tempered experience of reward is likely to be relevant to understanding both their typical cognitive, affective, and behavioral characteristics (i.e., trait level) as well as their risk for developing symptoms of depression, which is characterized in part by difficulties experiencing pleasure (APA, 2013). Although the mechanisms by which personality traits are linked to specific outcomes remain largely unknown, this perspective highlights the importance of and potential for incorporating personality research into models of psychopathology.

The Current Study

In the current study, our primary aim is to address the potentially artificial divide of personality traits and indices of psychopathology by comparing the neuroanatomical correlates of FFM traits to those of internalizing and externalizing psychopathology. Individual differences in brain morphometry have been linked to personality traits (e.g., Riccelli et al. 2017; DeYoung et al., 2010; Bjornebekk et al., 2013) as well as psychopathology, including disorders such as schizophrenia (e.g., Rimol et al., 2010), major depressive disorder (Foland-Ross et al., 2015), social anxiety disorder (Brühl et al., 2014), substance use (Thayer et al., 2017), and conduct disorder (Chumachenko et al., 2015). However, the degree to which the variations in neuroanatomical structure that are relevant to personality traits overlap with those relevant to psychopathology remains uncertain. Thus, to complete the primary aim of investigating the

shared neuroanatomical bases of personality and psychopathology, we conducted a two-step analytic approach.

Step 1. The first step of the current analyses was to examine the neuroanatomical correlates (i.e., cortical surface area, cortical thickness, cortical and subcortical gray matter volume) of FFM traits and of three psychopathology symptom variables (*Internalizing Psychopathology*, *Antisocial Behavior*, and *Substance Use*) for the purpose of creating neuroanatomical profiles (NAPs) of each personality trait and psychopathology variable in the brain. While substance use is generally considered to be a category of psychopathology that is subsumed under the construct externalizing behavior, we elected to use separate variables to capture a category of externalizing behaviors characterized by aggression and rule-breaking (*Antisocial Behavior*) and more specific substance use-related behaviors in another (*Substance Use*), in line with work suggesting these two separate from a higher-order externalizing factor in hierarchical models of psychopathology (i.e., Kotov et al., 2017). To create the NAPs, we used a parcellation-based approach to characterize the associations of personality traits and psychopathology symptoms to morphometry in the 68 cortical regions defined by the Desikan atlas (Desikan et al., 2006) and a subcortical segmentation approach to characterize their association with morphometry in 18 subcortical regions, selecting this approach over a voxelwise approach to facilitate the second step of our analytic approach by providing a manageable number of regions which could be compiled into neuroanatomical correlational profiles (i.e., NAPs).

Step 2. For the second step of the current analyses, we employed an intraclass correlation (ICC) profile matching approach (e.g., see McCrae, 2008 for a review) to compare the NAPs of FFM traits and indices of internalizing and externalizing psychopathology. Herein,

we operationalize NAPs as the column of values that results from correlating a trait or psychopathology index with one morphometric index (i.e., cortical surface area, thickness) in 68 cortical regions of the Desikan atlas, or in the 86 cortical and subcortical regions (i.e., cortical and sub-cortical volume). ICC analyses can be used to compare the absolute similarities of correlations derived from two or more measured variables (e.g., neuroanatomical correlates of Neuroticism compared with neuroanatomical correlates of *Internalizing Psychopathology*). By doing so, we were able to examine the extent to which traits and psychopathological symptoms are associated with common patterns of brain morphometry.

Hypotheses. Consistent with the links established in a prior meta-analysis (Kotov et al., 2010), we hypothesized that the NAPs of Neuroticism and Extraversion would be positively and negatively related to the NAPs of *Internalizing Psychopathology*, respectively. Similarly, given prior meta-analytic findings (e.g., Jones et al., 2011; Kotov et al., 2010) we expected the NAPs of Agreeableness and Conscientiousness to be negatively related to the NAPs of *Antisocial Behavior* and *Substance Use*. Consistent with HiTOP and previous meta-analytic findings, we hypothesized that low Agreeableness would be more strongly related to the *Antisocial Behavior* composite, while low Conscientiousness would be more strongly related to a *Substance Use* composite.

Methods

Participants

Structural MRI and self-reported personality and psychopathology data were collected from 1113 participants at Washington University as part of the Human Connectome Project between August 2012 and October 2015, and released in full on March 1, 2017 (see Table 1 for full participant information). Of these 1113, seven were excluded for not have full NEO-FFI data

and not having full Achenbach Adult Self-Report (ASR) data, one was excluded for not having full NEO-FFI data, one was excluded for not having full ASR data, and three were excluded for not having full substance use data. This yielded a final sample of 1101 participants. Informed consent was obtained for all participants (consent procedure detailed in Van Essen et al., 2013a). Of note, exclusion criteria included a history of severe psychiatric (e.g., schizophrenia) or substance abuse disorder, as operationalized by 1) participant report of diagnosis by treating physician, 2) hospitalization for two days or longer, and/or 3) pharmacological or behavioral treatment by a cardiologist, psychiatrist, neurologist, or endocrinologist for a period of 12 months or longer (Van Essen et al., 2013b, see Supplemental Table 1). Exclusion criteria also included history of neurological (e.g., traumatic brain injury) or medical disorders (e.g., cardiovascular disease, Mendelian genetic disease). Additionally, participants did not have any MRI contraindications such as unsafe metal implants or claustrophobia (for full details of inclusion and exclusion criteria, see Van Essen et al., 2013b).

Materials

NEO-FFI (Costa & McCrae, 1992). The NEO-FFI is a 60-item self-report measure of FFM personality traits. In the current sample, Cronbach's α ranged from .75 (*Openness*) to .84 (*Neuroticism*).

Achenbach Adult Self-Report (ASR; Achenbach & Rescorla, 2003). The ASR is a 123-item measure of adaptive functioning for adults (18-59) that includes items on behavior, emotional, and social problems. These items can be used to create 8 empirically based syndrome scales (*Anxiety/Depression*, *Withdrawnness*, *Somatic Complaints*, *Thought Problems*, *Attention Problems*, *Aggressive Behavior*, *Rule-Breaking Behavior*, *Intrusive Behavior*). From these, we derived an *Internalizing Psychopathology* composite (containing *Anxiety/Depression*,

Withdrawnness, and *Somatic Complaints*) and an *Antisocial Behavior* composite (containing *Aggression*, *Rule-Breaking*, and *Intrusiveness*). The current study focused on the two psychopathology composites, as well as a *Substance Use* composite (see below). 9 items from the ASR scales were redundant with items on the NEO-FFI (items: 3, 12, 35, 45, 48, 50, 103, 112) and 2 were redundant with the *Substance Use* Scale (items: 6 and 90); these were removed from all analyses to diminish concerns with criterion contamination.² Cronbach's α ranged from .69 (*Antisocial Behavior*) to .80 (*Substance Use*).

Semi-Structured Assessment for the Genetics of Alcoholism (SSAGA-II). The SSAGA-II (Bucholz et al., 1994) was conducted to gather information about recent substance use history. To create a substance use composite, we aggregated the number of symptoms of alcohol use disorder and cannabis use disorder endorsed and the reported frequency of use of five other illicit substances: cocaine, opiates, stimulants, hallucinogens, and sedatives. This resulted in a measure scaled zero to 14 spanning seven substances, with zero points indicating absence of problematic use, one point indicating moderately problematic use of a substance, and two points indicating severely problematic use of a substance.

Non-diagnostic screening questionnaire. A brief non-diagnostic screening questionnaire was given to participants to assess for possible panic disorder and agoraphobia (see Van Essen et al., 2013b).

MRI Data Acquisition and Processing

High-resolution T1-weighted structural images were acquired on a 3T Siemens Skyra scanner (Siemens AG, Erlanger, Germany) with a 32-channel head coil at a resolution of 0.7 mm³ isotropic (FOV = 224 x 240, matrix = 320 x 320, 256 sagittal slices; TR = 2400 ms and TE

²Of note, all items were removed prior to running any of the ICC analyses.

= 2.14 ms). The quality checking procedure completed to ensure all scans were of high quality has been documented by Marcus and colleagues (2013). Data were reconstructed and preprocessed using the Freesurfer pipeline (Dale, Fischl, & Sereno, 1999; Fischl, Sereno, & Dale, 1999; Fischl et al., 2004) in FreeSurfer Image Analysis Suite version 5.3 (<http://surfer.nmr.mgh.harvard.edu>; Fischl, 2012). See (Glasser et al., 2013; Van Essen et al., 2013b) for more details of acquisition, reconstruction, and preprocessing. Three morphometric indices were extracted using Freesurfer cortical parcellation (cortical thickness, cortical surface area, cortical gray matter volume) in 68 regions defined by the Desikan atlas (34 from each hemisphere). Additionally, subcortical segmentation was used to extract gray matter volume from 18 subcortical regions (nine corresponding regions from the left and right hemisphere). Estimated intracranial volume (eICV) was extracted for each participant for use as a covariate. Values for each index in each cortical region were exported into Statistical Package for Social Sciences (SPSS). Thus, the 68 Desikan-based cortical regions formed the basis of each participant's cortical thickness and area NAPs, and the 86 Desikan-based cortical and subcortical regions formed the basis of each participant's gray matter volume-based NAPs.

Data Analysis

Step 1. To create NAPs of personality traits and psychopathology, we generated partial correlations (controlling for age, sex, and eICV) between the each of the 68 cortical regions of the Desikan atlas (and the 18 subcortical regions for gray matter volume only) and both the FFM traits and internalizing/antisocial behavior/substance use variables. This resulted in a cortical surface area profile, a cortical thickness profile, and a gray matter volume profile for each of the five FFM traits and each of the three psychopathology variables. We also calculated simple zero-order correlations between all non-imaging study variables.

Step 2. All correlations from NAPs were Fisher's z-transformed and double entry ICCs were calculated between the NAPs of the FFM traits and the NAPs of the psychopathology variables (e.g., Miller, Reynolds, & Pilkonis, 2004). These correlations were then back-transformed to generate the ICC coefficient, which represents the level of absolute similarity between the two sets of correlations using the same scale as a standard Pearson's correlation. We conducted the ICCs between each trait and psychopathology variable separately for each metric (e.g., the cortical surface area NAP of a trait intra-class correlated with the cortical surface area profile of a psychopathology index NAP), then tested the absolute values of each trait-psychopathology ICC against one another using Steiger's z-tests to examine if the magnitude of the correlations were significantly different at $p < .005$, based on recent recommendations regarding thresholds for statistical significance (see Benjamin et al., 2018; Steiger, 1980). These represented the primary tests of our hypotheses regarding the similarity of the NAPs of the FFM traits and *Internalizing Psychopathology*, *Antisocial Behavior*, and *Substance Use* variables. Finally, given that some prior investigations have focused on the unique relations that result from residualized trait and psychopathology variables (e.g., Riccelli et al., 2017), we conducted exploratory analyses wherein we examined relations between the NAPs of residualized FFM traits (i.e., examining a trait while controlling for the four non-target traits and age, gender, and eICV) and the NAPs of residualized psychopathology indices (i.e., examining a psychopathology index while controlling for the two non-target psychopathology indices and age, gender, and eICV).

Results

Bivariate Relations among Study Variables

In general, the FFM traits correlated as expected with the internalizing and externalizing psychopathology indices (see Table 2). Neuroticism manifested a large positive correlation with the internalizing composite whereas Extraversion manifested a medium negative correlation with the internalizing composite. Agreeableness and Conscientiousness manifested small to medium negative correlations with all three psychopathology composites. Finally, Openness was generally unrelated to the internalizing or antisocial behavior composite, but demonstrated a small, positive relation to the substance use composite.

Creation of Neuroanatomical Profiles of FFM Traits and Psychopathology (Step 1)

Partial correlations of regional cortical thickness, surface area, and cortical/sub-cortical volume with the FFM traits are shown in Supplemental Tables 1, 2, and 3, and the reported relations were significant at the threshold of $p < .005$. In terms of cortical thickness, Neuroticism was positively related to thickness in the left caudal middle frontal gyrus, pars orbitalis, pars triangularis, and the superior frontal gyrus. In terms of cortical surface area, Neuroticism was negatively related to surface area in the left cuneus, pars triangularis, and superior parietal lobule, the right supramarginal gyrus, and the left and right superior frontal gyrus. In terms of volume, Neuroticism was negatively related to the left cuneus. Openness was negatively associated with cortical thickness in the left rostral middle frontal gyrus and superior parietal lobule. Openness was also positively related to cortical surface area in the left inferior temporal gyrus. In terms of volume, Openness was positively related to the left caudate and negatively related to the right transverse temporal cortex. Agreeableness was negatively associated with thickness in the left caudal middle frontal gyrus. Extraversion was positively related to surface area and volume in the right superior frontal gyrus. None of the cortical or sub-cortical associations with Conscientiousness reached statistical significance at the threshold of $p < .005$.

Full NAPs of psychopathology symptom variables are presented in Supplemental Tables 4, 5, and 6. Surface area in the right superior frontal gyrus was negatively related to *Internalizing Psychopathology*. Surface area in the left cuneus was negatively related to *Antisocial Behavior*. In terms of cortical thickness, *Substance Use* was negatively associated with the left caudal middle frontal gyrus, pars opercularis, rostral middle frontal gyrus, and frontal pole, as well as the left and right superior frontal gyrus. In terms of volume, *Substance Use* was negatively related to the left pars triangularis, rostral middle frontal gyrus, and amygdala, as well as right superior temporal lobe gyrus and transverse temporal cortex. Of note, despite reaching statistical significance, all of the reported effect sizes in Step 1 were small at most in magnitude; the largest effect size in magnitude was $r_{\text{partial}} = -.13$ (i.e., < 2% of variance) between Neuroticism and the right superior frontal gyrus (Supplemental Table 2).

Intraclass Correlations Comparing Neuroanatomical Profiles (Step 2)

Internalizing psychopathology. The NAPs of the *Internalizing Psychopathology* composite generally demonstrated medium to large³ ICCs with the NAPs of Extraversion and Neuroticism that were negative and positive, respectively (Table 3). The Agreeableness and Conscientiousness NAPs evinced medium, negative ICCs with the *Internalizing Psychopathology* composite NAPs. Of note, the magnitude of these relations varied by the morphometric index considered. For example, the value of the ICC between the Extraversion cortical area NAP and the *Internalizing Psychopathology* cortical area NAP was the largest of the three (i.e., cortical thickness, cortical area, volume) in magnitude, while Neuroticism's cortical area NAP was the Neuroticism NAP that bore the smallest ICC in magnitude with the *Internalizing Psychopathology* NAPs.

³ By conventional standards for estimating magnitude of effect size (see Cohen, 1992)

Antisocial behavior. The Agreeableness NAPs demonstrated medium to large, negative ICCs with each of the *Antisocial Behavior* composite NAPs (Table 4). The Conscientiousness NAPs also showed consistently negative ICCs with all *Antisocial Behavior* NAPs, but the magnitude of effect size ranged from small to medium depending on the morphometric index considered. Similarly, the Neuroticism and Openness NAPs generally displayed null relations with the *Antisocial Behavior* NAPs, with the exception of the cortical/sub-cortical volume Neuroticism NAP and cortical thickness Openness NAP, which bore medium positive and negative relations to their *Antisocial Behavior* counterparts, respectively.

Substance use. The Conscientiousness NAPs bore medium to large, negative relations with all *Substance Use* NAPs, and the Extraversion NAPs bore medium, negative relations with all *Substance Use* NAPs (Table 5). The Neuroticism, Openness, and Agreeableness NAPs generally exhibited null relations to the *Substance Use* NAPs, with two exceptions: the cortical thickness NAPs of Neuroticism and Openness bore, respectively, large and medium relations to their respective *Substance Use* counterparts.

Steiger's z-tests. Differences across the NAPs were deemed significant at $p < .005$. In terms of hypotheses, the Extraversion NAPs demonstrated significantly larger ICCs to *Internalizing Psychopathology* NAPs than Neuroticism, except for the cortical thickness NAP which showed comparably large relations. In general, the Extraversion and Neuroticism NAPs bore stronger relations to *Internalizing Psychopathology* NAPs than did the NAPs for any other traits, with the exception of cortical surface area, where the Neuroticism, Agreeableness, and Conscientiousness NAPs showed comparably strong relations. The Agreeableness NAPs showed larger ICCs to the *Antisocial Behavior* NAPs than did any other trait, with the exception of the cortical thickness Openness NAP which demonstrated a comparably strong relation. Similarly,

the Conscientiousness cortical surface area NAP showed the strongest relation to the cortical surface area *Substance Use* NAP. The Extraversion and Conscientiousness cortical/sub-cortical volume NAPs bore comparable relations to the *Substance Use* cortical/sub-cortical volume NAP. The Neuroticism cortical thickness NAP displayed the largest relation to the *Substance Use* counterpart.

Exploratory covariate analyses. The results of the exploratory analyses approximately mirrored the primary findings (see Supplemental Tables 7-9). In general, the residualized Agreeableness and Conscientiousness NAPs were the strongest correlates of the *Antisocial Behavior* and *Substance Use* NAPs, respectively. The residualized Extraversion and Neuroticism NAPs generally maintained hypothesized relations to the residualized *Internalizing Psychopathology* NAPs, but the magnitude of the Neuroticism-*Internalizing Psychopathology* NAPs relations decreased substantially.

Discussion

Although personality has acted as a guiding framework for investigating how patterns of behavior, cognition, and affect relate to a wide range of important psychological outcomes (e.g., Ozer and Benet-Martinez, 2006), historically there has been an artificial barrier erected between personality and psychopathology. We used data from the Human Connectome Project, a large neuroimaging database, to address the neuroanatomical similarity of FFM traits and psychopathology in two steps. In the first step, we characterized FFM personality traits and three psychopathology variables (*Internalizing Psychopathology*, *Antisocial Behavior*, *Substance Use*) in terms of their associations with cortical surface area, cortical thickness, and gray matter volume. This facilitated the second step, in which we investigated the degree to which these neuroanatomical characterizations of FFM traits and psychopathology overlap.

In Step 1, the patterns of correlation that make up the NAPs are consistent with other studies focused on the regional morphometric correlates of personality (Riccelli et al., 2017; Gray et al., 2018; Owens et al., 2018), with some of the largest correlations of morphometry and personality being found in the lateral prefrontal cortex (i.e., superior, middle, and inferior frontal gyrus). There were distinct regions and metrics with larger correlations to specific traits, such as thickness of the left caudal middle frontal gyrus with Agreeableness, area of the right superior frontal gyrus with Neuroticism, volume of the transverse temporal cortex with Openness. Several of these regions/metrics were also significantly associated with the psychopathology variables investigated, and we quantitatively tested the degree of the overall similarities in Step 2.

To test these similarities in Step 2, we used the complete NAPs generated within Step 1 for each FFM trait, as well as the NAPs for indices of *Internalizing Psychopathology*, *Antisocial Behavior*, and *Substance Use*. We conducted a profile matching approach, in which we compared the trait NAPs to psychopathology index NAPs, to assess their absolute similarity. Our trait-internalizing psychopathology hypotheses were generally supported. The NAPs of Neuroticism and Extraversion generally displayed large ICCs to the *Internalizing Psychopathology* composite NAPs that were positive and negative, respectively, whereas the Agreeableness and Conscientiousness NAPs displayed small-to-medium relations to this composite.

Our hypotheses regarding trait-externalizing psychopathology relations also received relatively strong support, specifically with regard to low Agreeableness. The Agreeableness NAPs demonstrated medium to large, negative ICCs to the *Antisocial Behavior* NAPs, and while the Conscientiousness NAPs were significantly smaller, they were in the expected direction. Conversely, the NAP for Neuroticism demonstrated smaller and less consistent relations with the

Antisocial Behavior NAPs, reflecting the smaller and less consistent role of this dimension in antisocial behavior and aggression (e.g., Jones et al., 2011). With regard to *Substance Use*, the Conscientiousness NAPs generally displayed the most consistent relations, although negative relations were also observed for the Extraversion NAPs. Of note, the magnitude and direction of the Neuroticism and Openness NAPs' ICCs to the *Antisocial Behavior* composite NAPs and the *Substance Use* composite varied greatly in magnitude and direction by neuroanatomical metric. There is not yet an integrated theory for how the different features of brain morphometry produce individual differences in behavior. However, the finding of different relations of cortical thickness and surface area with externalizing subscales is not inconsistent with prior literature, which has indicated different cognitive, genetic, and clinical correlates of different morphometric indices (Nissim et al., 2017; Panizzon et al., 2009; Rimol, et al., 2012; Winkler et al., 2018). We believe the current findings highlight the need to use multiple neuroanatomical metrics for a comprehensive understanding of these associations and for future work developing an integrated model of how these morphometric features differentially relate to behavior.

In terms of our exploratory analyses, the hypothesized relations between FFM traits and psychopathology indices were still found when the residualized variables were investigated. We note that the use of residualized (or “partialled”) variables can create substantial problems with interpretation, in that it is often unclear what a variable represents once a substantial portion of its shared variance is removed (Lynam, Hoyle, & Newman, 2006; Sleep, Lynam, Hyatt, & Miller, 2017). For example, the internalizing and externalizing psychopathology composites were correlated at $r = .58$, and so when one of the variables is partialled from the other, 34% of the reliable shared variance is removed. Although this strategy is often used to examine the “unique” relations of one variable over another, it is difficult to know what a variable represents

when it has been substantially altered in such a manner. Thus, it is our position that the analyses conducted without controlling for the non-target traits and psychopathology indices are the most accurate representation of the neuroanatomical similarity between FFM traits and psychopathology. However, these exploratory analyses suggest that the similarities in the neuroanatomical correlates of FFM traits and psychopathology symptoms are detectable using either analytic approach, both of which are common used in the personality neuroscience literature.

Implications

The current results converge with modern taxonomies of psychopathology (i.e., HiTOP) and support models that posit personality traits and psychopathological symptoms/syndromes have similar neuroanatomical underpinnings and are related to the same higher-order factors of psychopathology. Although the maladaptive traits defined in the HiTOP model are given different labels (see Krueger, Derringer, Markon, Watson, & Skodol, 2012), there is ample evidence suggesting that basic trait frameworks like the FFM can accurately capture most maladaptive phenotypes (e.g., Lynam & Miller, 2015; Widiger, Trull, Clarkin, Sanderson, & Costa, 1994). Consistent with this literature (e.g., Clark & Watson, 1991), our results suggest similar neuroanatomical correlates of Neuroticism (i.e., Negative Affectivity) and (low) Extraversion (i.e., Detachment) to those of internalizing psychopathology. Similarly, the current results suggest low Agreeableness (i.e., Antagonism) and low Conscientiousness (i.e., Disinhibition) have comparable neuroanatomical correlates to externalizing psychopathology and substance use, respectively. Of note, in the HiTOP model, the disinhibited and antagonistic spectra are thought to contribute to antisocial behavior approximately equally. The current results suggest that at the neuroanatomical level, Antagonism demonstrates more consistent

relations with an externalizing composite which includes behaviors such as aggression and criminality than does Disinhibition, consistent with non-brain-based associations (Jones, et al., 2011; Miller & Lynam, 2001). However, when substance use is examined separately, Disinhibition appears to be the more robust correlate, also consistent with meta-analyses emphasizing Disinhibition's role in problematic substance use (Kotov et al., 2010; Malouff, Thorsteinsson, & Schutte, 2006).

Limitations and Considerations

A key limitation of this study is the use of a relatively healthy population compared to a treatment-seeking sample, as individuals with significant history of severe psychiatric and medical disorders were excluded. Therefore, generalizability to NAPs of psychopathology indices in clinical populations is uncertain. We note that our sample reported a range of both internalizing and externalizing symptoms (see Table 1). Specifically, there were only 43 participants (out of 1101) endorsing no internalizing symptoms and 50 (out of 1101) endorsing no externalizing symptoms. Although approximately 10% of the sample met criteria for a lifetime major depressive episode, which is lower than a recent epidemiological estimate of major depressive disorder in adults in the United States of 20.6% (Hasin et al., 2018), nearly 20% of the current sample reported experiencing five or more symptoms at some point (i.e., not concurrently) in their lifetime. Furthermore, over 20% percent met criteria for an alcohol use disorder at some point in their lifetime, which is slightly more frequent than the general population (Grant et al., 2015). Thus, while this was not a clinical sample, there is evidence to demonstrate sufficient variance in internalizing and externalizing psychopathology to justify the current analyses. In fact, we believe that our results may actually be more robust if individuals with severe psychopathology had been included, as this would have increased the variability in

psychopathology and personality. In other words, we believe this is a limitation that serves to temper, not inflate, the current results.

Another limitation is our use of self-report of clinical symptoms. While this is a common mode of assessment for both personality traits and psychopathological symptoms, especially in very large samples such as this one, it will be important to test these relations in future research using additional methodologies such as interview-ratings and informant reports. A final consideration is analytic method by which we characterized the neuroanatomical bases of FFM traits and psychopathology indices. We elected to use a parcellation-based approach using the Desikan atlas in order to facilitate our primary aim: examining the neuroanatomical overlap between personality traits and psychopathology indices. This methodology was chosen to serve the purpose of creating NAPs rather than generating the most reliable characterization of the regions associated with personality and psychopathology. Because of its greater flexibility within structures of the brain (e.g., subunits of the superior frontal gyrus) and superior ability to reduce type II error through cluster-extent thresholding, a voxelwise analysis with proper multiple comparison correction would likely provide a more precise and reliable characterization of the regions most important to each personality trait. We elected the current strategy because characterizing the specific regions most important to each FFM traits was not the primary purpose of the current study, and appropriate voxelwise analyses of the neuroanatomical bases of personality have already been completed by other studies using the HCP sample (Gray et al., 2018; Owens et al., 2018; Riccelli et al., 2017). It is notable that similar regions were found to have the largest correlations in magnitude in the current parcellation-based analyses as were found in other studies using a voxelwise approach, suggesting that the neuroanatomical bases of personality are generally robust to different approaches to parsing structures of the brain.

However, it should be reiterated that despite statistical significance, the current analyses suggest that the effect sizes of relations between morphometric indices and personality traits are uniformly small in magnitude.

A final consideration to note regards a critique we received at several points while completing this work. Namely, if we know the bivariate relation between two constructs (e.g., Neuroticism and depression), have we learned anything new by establishing that they have similar neural correlates? We propose three reasons why we believe the results presented herein are an important advancement beyond the basic bivariate relation. First, although we suspect that these results may not come as particularly surprising to personality and psychopathology researchers, we hope that the current work serves as a demonstration for any remaining skeptics who doubt that personality and difficulties with mental health functioning are fundamentally related concepts. In fact, they are so intertwined that personality traits and the psychopathology indices closely associated with them are characterized by similar brain structures across multiple metrics. While this link may be intuitive to personality researchers, we note that this is perhaps the first time it has been examined in this manner.

Second, we believe that the results of the current manuscript are important above and beyond the simple bivariate relations between personality and psychopathology because we observed interesting differences between the bivariate relations (i.e., Table 2) and the ICCs (i.e., Tables 3-5). For example, we hypothesized that given their meta-analytic relation at the bivariate level, the Neuroticism NAPs would demonstrate large ICCs with the Internalizing Psychopathology NAPs. Indeed, in this sample, their bivariate correlation is $r = .61$. However, the results of the ICC analyses suggest that the magnitude of their neuroanatomical overlap is relatively smaller than their bivariate relation (i.e., ICCs ranging from .30 to .44). Alternately,

although Extraversion and internalizing psychopathology were correlated at $r = -.38$ at the bivariate level, results of the NAPs analyses suggest that they are more largely overlapping at the neuroanatomical level (i.e., ICCs ranging from $-.41$ to $-.58$). As a similar example, although Conscientiousness and Substance Use were only correlated at $r = -.17$ at the bivariate level, the ICC analyses suggest that their NAPs are much more overlapping than the bivariate relation may suggest (i.e., ICCs ranging from $-.37$ to $-.50$). Of course, this complexity does not even broach the important differences observed across the three brain metrics (i.e., cortical thickness, cortical surface area, and cortical/sub-cortical volume) used. In sum, we believe that these intriguing differences between the bivariate and neuroanatomical level of analysis provide support for the notion that the neuroanatomical similarity of personality traits and psychopathology cannot be summarized neatly by a single bivariate correlation value.

Lastly, we believe that demonstrating support for the neuroanatomical overlap of personality and psychopathology also serves to help integrate these two literatures. Specifically, a major benefit of this work is that researchers who are studying a specific form of internalizing psychopathology (e.g., depression) as it relates to neural processes now have the benefit of being able to leverage any extant, relevant neuroimaging work on Neuroticism, or vice versa. Research on basic personality traits has made substantial contributions to our understanding of Axis II personality disorders (e.g., Samuel & Widiger, 2008); now, in line with a recently proposed model of psychopathology (i.e., HiTOP), we believe the current work suggests that personality may also be able to contribute substantially to Axis I disorders as well, given that multiple levels of analysis suggest that they are very similar (e.g., Wright & Simms, 2015).

Conclusions

In summary, in the largest study of neuroanatomical similarity of personality and psychopathology to date, hypothesized pairs of FFM traits and indices of internalizing and externalizing psychopathology demonstrated similar patterns in their relationships to brain structure. Overall, these findings are consistent with theoretical accounts suggesting that personality and psychopathology are not independent constructs, but are, rather, phenomena sharing similar underlying neural structures. The current results have nosological and clinical implications and we encourage future researchers in this area to consider examining a wide range of regions and structural metrics, such as investigating into whether similar relationships exists between personality and psychopathology in regard to white matter microstructure, which has been linked to personality (e.g., Bjørnebekk, et al. 2013) and psychopathology (e.g., Whalley et al., 2015). Additionally, given the field-wide shift to a network-based approach to neuroscience (as opposed to a regions of interest approach; Medaglia, Lynall, & Bassett, 2015), we encourage work examining how specific neural networks and are relevant to understanding personality traits and other individual differences which are inextricably related to symptoms of psychopathology. Finally, we encourage research into the mechanisms by which personality traits are expressed, especially insofar as these mechanisms relate to important life outcomes like psychopathology.

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Table 1

Demographic characteristics (N = 1101)

	M (SD) or %
Sex	
Male	45.8%
Female	54.2%
Age	28.8 (3.7)
Race	
White or Caucasian	74.8%
Black or African American	15.1%
Asian American, Native Hawaiian, or other Pacific Islander	5.7%
Native American	.2%
More than one race	2.5%
Not sure or unknown	1.7%
Ethnicity	
Hispanic or Latino	8.5%
Not Hispanic or Latino	90.3%
Not sure or unknown	1.2%
Income	
\$1,000-\$9,999/year	7.0%
\$10,000-\$19,999/year	7.9%
\$20,000-\$29,999/year	12.5%
\$30,000-\$39,999/year	12.0%
\$40,000-\$49,999/year	10.3%
\$50,000-\$74,999/year	21.2%
\$75,000-\$99,999/year	13.4%
\$100,000-\$149,999/year	15.6%
Years of Education	14.92 (1.80)
Lifetime Depressive Episode	9.4%
Lifetime 5 or more Major Depressive Disorder Symptoms	17.2%
Lifetime Potential* Panic Disorder Diagnosis	7.2%
Lifetime Potential Agoraphobia Diagnosis	6.8%
Symptoms of Childhood Conduct Disorder	39.3%
Lifetime Alcohol Use Disorder	20.8%
Lifetime Cannabis Use Disorder	9.2%

*note: panic disorder and agoraphobia diagnoses are herein considered “potential” because they indicate elevated response levels on a non-diagnostic screen.

Table 2

Bivariate correlations among FFM Traits and Internalizing/Externalizing Indices.

	<i>1.</i>	<i>2.</i>	<i>3.</i>	<i>4.</i>	<i>5.</i>	<i>6.</i>	<i>7.</i>
<i>1. Neuroticism</i>	-	-	-	-	-	-	-
<i>2. Extraversion</i>	-.35	-	-	-	-	-	-
<i>3. Openness</i>	.01	.10	-	-	-	-	-
<i>4. Agreeableness</i>	-.29	.28	.09	-	-	-	-
<i>5. Conscientiousness</i>	-.40	.26	-.13	.23	-	-	-
<i>6. Internalizing</i>	.61	-.38	.07	-.28	-.28	-	-
<i>7. Antisocial Behavior</i>	.37	-.02	.11	-.44	-.32	.58	-
<i>8. Substance Use</i>	.07	.00	.21	-.13	-.17	.09	.32

Table 3

ICC coefficients between FFM traits and *Internalizing Psychopathology* by morphometric index

Trait	<i>Internalizing Psychopathology</i>		
	Area	Thickness	Volume
<i>Neuroticism</i>	.30 ^a (.25 to .35)	.42 ^c (.37 to .47)	.44 (.39 to .49)
<i>Extraversion</i>	-.58 (-.62 to -.54)	-.41 ^c (-.46 to -.36)	-.55 (-.59 to -.51)
<i>Openness</i>	-.18 ^b (-.24 to -.12)	-.34 ^c (-.39 to -.29)	.14 ^d (.08 to .20)
<i>Agreeableness</i>	-.28 ^{ab} (-.33 to -.22)	-.35 ^c (-.40 to -.30)	-.21 ^{de} (-.27 to -.15)
<i>Conscientiousness</i>	-.22 ^{ab} (-.28 to -.16)	-.11 (-.17 to -.05)	-.31 ^e (-.36 to -.26)

Note: values inside parentheses represent 95% confidence interval; large effect sizes (i.e., correlations where the 95% confidence interval includes a value larger than or equal to |.50|) are **bolded**; superscripts^{a-e} are used to denote sets of traits where Steiger's z-tests suggest that these ICC values are *not* statistically different from one another at $p < .005$; area = cortical surface area; thickness = cortical thickness; volume = cortical and sub-cortical volume; FFM traits and psychopathology indices covary with age, gender, and eICV.

Table 4

ICC coefficients between FFM traits and *Antisocial Behavior* by morphometric index

Trait	<i>Antisocial Behavior</i>		
	Area	Thickness	Volume
<i>Neuroticism</i>	-.03 ^a (-.09 to .03)	.11 ^c (.05 to .17)	.38 ^e (.33 to .43)
<i>Extraversion</i>	-.24 ^b (-.29 to -.18)	.08 ^c (.02 to .14)	-.12 ^f (-.18 to -.06)
<i>Openness</i>	.02 ^a (-.04 to .08)	-.40 ^d (.35 to .45)	.07 ^f (.01 to .13)
<i>Agreeableness</i>	-.42 (-.47 to .37)	-.49^d (-.53 to -.44)	-.49 (-.53 to -.44)
<i>Conscientiousness</i>	-.28 ^b (-.33 to -.22)	-.07 ^c (-.13 to -.01)	-.39 ^e (-.44 to -.34)

Note: values inside parentheses represent 95% confidence interval; large effect sizes (i.e., correlations where the 95% confidence interval includes a value larger than or equal to |.50|) are **bolded**; superscripts^{a-f} are used to denote sets of traits where Steiger's z-tests suggest that these ICC values are *not* statistically different from one another at $p < .005$; area = cortical surface area; thickness = cortical thickness; volume = cortical and sub-cortical volume; FFM traits and psychopathology indices covary with age, gender, and eICV.

Table 5

ICC coefficients between FFM traits and *Substance Use* by morphometric index

Trait	<i>Substance Use</i>		
	Area	Thickness	Volume
<i>Neuroticism</i>	.03 ^a (-.03 to .09)	-.64 (-.67 to -.60)	.16 ^c (.10 to .22)
<i>Extraversion</i>	-.27 (-.32 to -.21)	-.41 ^b (-.46 to -.36)	-.32 ^d (-.37 to -.27)
<i>Openness</i>	.09 ^a (.03 to .15)	.37 ^b (.32 to .42)	.08 ^c (.02 to .14)
<i>Agreeableness</i>	-.03 ^a (-.09 to .03)	.10 (.04 to .16)	-.13 ^c (-.19 to .07)
<i>Conscientiousness</i>	-.49 (-.53 to -.44)	-.50 (-.54 to -.45)	-.37 ^d (-.42 to -.32)

Note: values inside parentheses represent 95% confidence interval; large effect sizes (i.e., correlations where the 95% confidence interval includes a value larger than or equal to |.50|) are **bolded**; superscripts^{a-d} are used to denote sets of traits where Steiger's z-tests suggest that these ICC values are *not* statistically different from one another at $p < .005$; area = cortical surface area; thickness = cortical thickness; volume = cortical and sub-cortical volume; FFM traits and psychopathology indices covary with age, gender, and eICV.