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Editor's choice

Special Issue: Preregistered Studies of Personality Development and Aging Using Existing Data

Associations Between Personality Traits and Cognitive Resilience in Older Adults

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Abstract

Objectives: The goal of this paper was to examine associations between personality traits and resilience to neuropathologic burden.

Method: Using data from the Religious Orders Study and the Rush Memory and Aging Project, we identified a total of 1,375 participants with personality, cognitive, and post-mortem neuropathology data. We regressed cognition onto pathology and extracted the residuals as an indicator of cognitive resilience. We then modeled the effect of Big Five personality traits on cognitive resilience, adjusting for demographics, APOE status, medical comorbidities, and cognitive activity. The analytic plan was preregistered prior to data access or analysis, and all scripts and outputs are available online.

Results: Higher neuroticism was associated with greater vulnerability to pathology. Results from exploratory analyses suggest that higher conscientiousness was associated with less cognitive decline relative to the amount of pathology, or greater resilience. Education and cognitive activity did not moderate these associations.

Discussion: Personality may have a pathoplastic effect on neuropathology, as low neuroticism and high conscientiousness are associated with better function despite neuropathologic burden.

Keywords: Big Five personality, Cognitive resilience, Individual differences, Preregistration, Neuropathology

It is common among older adults to have some amount of dementia-related neuropathology in their brains when they die. Autopsy studies of cognitively normal older adults have shown that roughly 30%–40% had the plaques and tangles that are hallmarks of Alzheimer's disease (AD; Bennett et al., 2006; Kapasi et al., 2017). In addition to Alzheimer's associated pathology, many other pathologies are often present in the brains of older adults including vascular disease, Lewy Bodies, and the newly characterized transactive response DNA-binding protein 43 (TDP-43; James et al., 2016; Kapasi et al., 2017). These pathologies correspond with the loss of cognitive functioning that is typical for most individuals with a given disease. However, there is growing evidence that many older adults with neuropathology do not present with dementia-related symptoms. These are individuals who are able to live relatively symptom free despite considerable neuropathology, and are not known to harbor such pathology until a post-mortem autopsy is conducted. In other words, some older adults are resilient to the losses taking place in their

brains, and are able to tolerate higher levels of the disease before showing signs and symptoms. Some adults are able to live their final years of life with better cognitive function and less decline than expected given the amount of Alzheimer's or other related disease in their brain, or in other words, are resilient to neurodegenerative pathology. Compared to others with the same amount of neuropathology, some individuals remain relatively asymptomatic (James and Bennett, 2019). Researchers have identified a number of psychological factors, such as personality traits, depressive symptoms, and affect, that are related to cognitive aging, and may put individuals at greater risk of, or protect against, the development of Alzheimer's or related dementias (ADRD). The goal of this paper is to examine whether personality traits are associated with discordances between cognitive function/change and post-mortem autopsy diagnosis of Alzheimer's and related neuropathology (Negash et al., 2013).

Cognitive Resilience

It has been documented that many individuals who maintain cognitive function throughout older adulthood (or only display normal cognitive decline) are revealed upon autopsy to have lived asymptomatically with substantial neurodegeneration and neuropathology such as the presence of a large number of neuritic plaques, neurofibrillary tangles, hyperphosphorylated TDP-43, and hippocampal atrophy (James et al., 2016). These individuals have greater cognitive functioning than expected given the level of pathology. In other words, they display high resilience to pathology (Hohman et al., 2016). On the other hand, individuals may demonstrate significant cognitive decline that is not related to their level of neuropathology; one study showed that only 40% of cognitive decline is explained by known neuropathologies (Boyle et al., 2013). The opposite has also been observed: individuals who demonstrate significant cognitive decline throughout older adulthood can display minimal signs of neurodegeneration at autopsy. These individuals lived their final years with worse cognitive abilities than expected (i.e., low resilience). We have previously employed this continuous measure of resilience in prior research (Bennett et al., 2006; Negash et al., 2013). An increasing body of evidence suggests that as many as 30%–50% of individuals without cognitive impairment have substantial neuropathology at autopsy (Balsis et al., 2005; Driscoll and Troncoso, 2011).

Individual Differences in Resilience

The presence and extent of this neural reserve capacity does not occur at random, and has been linked to a number of factors that are associated with cognitive abilities and neuropathology, including psychological factors, lifestyle factors, genetics, and other disease comorbidities (James and Bennett, 2019). Limited evidence has suggested early life socioeconomic status (SES), reading ability, and lifelong cognitive engagement as potential factors that promote the "resilient" discordant phenomenon (Negash et al., 2013). However, there may be non-cognitive factors that are associated with cognitive resilience. One such factor is personality: personality traits are associated with cognitive abilities (Graham and Lachman, 2014; Sutin et al., 2011), cognitive decline (Luchetti et al., 2016; Wilson, Capuano, et al., 2015), and dementia risk (Kaup et al., 2019; Low et al., 2013; Terracciano and Sutin, 2019). Across these bodies of work, neuroticism, conscientiousness, and openness tend to be the most closely associated with all cognitive outcomes with extraversion and agreeableness showing more limited evidence.

To provide a theoretical framework to help explain these associations, some have suggested that individuals higher in neuroticism have greater arousal, higher stress reactivity, and more hypothalamic–pituitary–adrenal axis activation, which, over the life course, may make an individual more vulnerable to cognitive decline or the development of neuropathology (Chapman et al., 2012; Neupert et al., 2008). Furthermore, individuals higher in openness or conscientiousness may be more committed to engaging in stimulating activities that help maintain cognitive function throughout older adulthood (Sharp et al., 2010; Wilson et al., 2007). Put differently, high levels of certain personality traits may be associated with greater cognitive reserve (Stern, 2012). To date, very little work has examined whether personality traits are associated with cognitive resilience, although some have suggested that this may be the case (James and Bennett, 2019). For example, Terracciano et al. (2013) compared individuals who were asymptomatic (dementia free in vivo but with neuropathology post-mortem) with those who were not and found that they tended to be higher in conscientiousness and lower in neuroticism. This study created a binary indicator of resilience, assigned participants to either the "asymptomatic" group (resilience) or not, then compared the personality traits of individuals in the two groups. The current study extends this study by modeling the associations between cognitive functioning and neuropathic indicators using regression, thereby yielding a continuous (rather than binary) residual-based measure of resilience. Subsequently, personality traits plus covariates were utilized as predictors of this continuous resilience outcome. This evidence for the personality trait association with cognitive resilience suggests that personality may follow a pathoplastic model, such that personality influences the presentation, course, or the outcome of neuropathology (Segerstrom, 2018).

As such, the current study examined whether personality traits that have been consistently associated with cognitive abilities are associated with cognitive/pathology discordance, or cognitive resilience. In other words, is personality associated with whether people perform better or have less decline than expected for their given level of pathology? This would suggest that personality may serve as a protective or risk factor in relation to the neurodegeneration

taking place in their brains. We expect that openness and conscientiousness will be associated with higher resilience, while neuroticism will be associated with lower resilience. We also hypothesize that agreeableness and extraversion will be associated with higher resilience, although given the limited prior evidence regarding these traits, we are less confident in these predictions.

The Current Study

Recent work using data from the same study as the current project has found that mixed pathologies are prevalent in both individuals with and without clinical dementia of the Alzheimer's type (Bennett et al., 2006; James et al., 2016), and that conscientiousness is associated with cognitive decline after adjusting for neuropathologic burden (Wilson, Capuano, et al., 2015). The current project extended this work by examining the associations between Big Five personality traits and cognitive resilience. We also extended the work of Terracciano et al. (2013) by using a continuous indicator of resilience and with a much larger sample size. Our primary aim was to test the main effects of each personality trait on the indicators of resilience.

Method

We identified two studies with appropriate data for addressing the above described research questions: The Religious Orders Study (ROS) and the Rush Memory and Aging Project (MAP).

The ROS is a longitudinal, epidemiologic clinical-pathologic cohort study of aging and AD that enrolls older Catholic nuns, priests, and brothers from more than 40 groups across the United States. Participants (N = 1,200) do not have known dementia at baseline and agree to annual clinical evaluation, cognitive testing, and brain and other tissue donation after death (Bennett et al., 2018; Bennett, Schneider, Arvanitakis, et al., 2012). Enrollment began in 1994 and is ongoing. Clinical evaluations and cognitive assessments occur annually, and all Big Five personality traits were assessed in 1994 using a shortened form of the NEO Five-Factor Inventory (NEO-FFI). Four of the 12 items for neuroticism were reverse-coded and 1 of the 6 items for extraversion was reverse-coded (Costa and McCrae, 1989).

The *Rush Memory and Aging Project (MAP)* is a longitudinal, epidemiologic clinical-pathologic cohort study of aging and AD. Participants are older adults recruited from retirement communities and subsidized senior housing facilities throughout Chicago land and northeastern Illinois. Participants do not have known dementia at baseline and agree to annual clinical evaluation, cognitive testing, and brain and other tissue donation after death (Bennett et al., 2018; Bennett, Schneider, Arvanitakis, et al., 2012). Enrollment began in 1997 and is ongoing. Clinical evaluations and cognitive assessments occur annually. Neuroticism and extraversion were assessed in 2004, while conscientiousness was assessed in 2008, using a shortened form of the NEO-FFI. Openness and agreeableness were not assessed in MAP. Four of the 12 items for neuroticism were reverse-coded and 1 of the 6 items for extraversion was reverse-coded. The same items were used in both cohorts (Costa and McCrae, 1989). As of 2016, 85% of the ROS/MAP individuals who died with no dementia had some form of dementia-related pathology (James et al., 2016).

Measures

Global cognition

Cognitive performance was evaluated annually using 17 tests assessing 5 cognitive domains (episodic memory, semantic memory, working memory, perceptual orientation, and perceptual speed) (Wilson, Boyle, et al., 2015). Scores from each test were z-scored, averaged together, then re-standardized, resulting in a single global cognition score for each annual assessment. For the primary analyses, we used the participants' final cognitive assessment prior to death. For the exploratory longitudinal analysis, we used the global cognition score from all available measurement occasions.

Neuropathologic burden

Our study used the following indicators of pathology: beta-amyloid, paired-helical-filament (PHF) tau tangles, Lewy body disease, vascular pathologies (multiple macroinfarcts or cortical microinfarcts, moderate-to-severe atherosclerosis, arteriolosclerosis, and cerebral amyloid angiopathy), hippocampal sclerosis, and TDP-43. The pathologies of individual conditions tend to be highly correlated (Bennett et al., 2004; Wilson, Nag, et al., 2013a). Depending on the distribution of a given pathologic marker, they were treated as either a continuous measure with higher scores indicating a greater amount of a given marker (e.g., AD pathology, cerebral amyloid angiopathy, or TDP-43), or as a binary indicator of the pathologic marker being either present or absent (e.g., hippocampus sclerosis, gross/microinfarcts, Lewy bodies, atherosclerosis, arteriolar sclerosis) (James et al., 2019; Wilson et al., 2019). All were assessed using post-mortem neuropathologic examination, the objective of which was to obtain quantitative indices of common diseases associated with age-related cognitive loss.

Collection of these data was completed via autopsy. Brain tissue was removed, sectioned, and persevered via a standard protocol (Schneider et al., 2009). One centimeter coronal cuts were done on each hemisphere, and then examined for gross cerebral infarcts. Using hematoxylin and eosin stains, microinfarcts were identified in six cortical, two subcortical, and one midbrain region of one hemisphere (Arvanitakis et al., 2011). Using beta-amyloid immunostaining across the midfrontal, inferior temporal, angular, and calcarine cortex, cerebral *beta-amyloid*

angiopathy was assessed. *Meningeal and parenchymal vessel beta-amyloid deposition* in each region was assessed using a 5-point scale (no deposition, scatter segmental but no circumferential deposition, circumferential deposition up to 10 vessels, circumferential deposition up to 75% of region, and circumferential deposition over 75% of region). In this analysis, the average of all regional scores was used as a composite beta-amyloid measure (Boyle et al., 2015). Visual inspection of the vessels of the circle of Willis was used to identify the presence of *atherosclerosis*, and hematoxylin- and eosin-stained sections of the anterior basal ganglia were used to identify *arteriolar sclerosis* (Arvanitakis et al., 2016). Both atherosclerosis and arteriolar sclerosis were treated as binary indicators, and graded as either moderate/severe, or absent if inspections suggested less severe presence.

Neuritic plaques, diffuse plaques, and neurofibrillary tangles were identified in five brain regions using a modified Bielschowsky silver stain. A single continuous measure for pathology was created by scaling each region score (counts for each pathology divided by the standard deviation), and then averaging those scores across the regions (Bennett et al., 2004). *TDP-43 cytoplasmic inclusions* were detected in six brain regions using monoclonal antibodies to phosphorylated TDP-43 (p5409/410; 1:100) (Neumann et al., 2009). Inclusion density was assessed, by region, using 6-point scale; the regional ratings were then averaged, resulting in a single composite index of TDP-43 pathology (Nag et al., 2015; Wilson, Yu, et al., 2013b). *Hippocampal sclerosis* was classified using hematoxylin and eosin stain inspection for severe neuronal loss and gliosis in the hippocampus or subiculum (Nag et al., 2015, 2017). Finally, a monoclonal antibody to alpha-synuclein across the substantia nigra, anterior cingulate cortex, entorhinal cortex, midfrontal cortex, superior or middle temporal cortex, and inferior parietal cortex was used to identify *Lewy bodies* (Schneider et al., 2006).

A standard protocol is followed when a new member is hired to the staff collecting β-amyloid, tangles, and TDP-43 data: The new rater is given between 50 and 100 slides to rate, that have previously been rated by a rater with more experience. The slides provided to the new hire are specifically collected to contain a representative range of pathology. We evaluated the within slide variation due to rates by calculating the percentage of variation in the square-root transformed value of amyloid. We typically find that this variation is less than 5%. A neuropathologist reviews the pathologist for cerebrovascular and Lewy body disease. All raters are certified on practice slides prior to participating in data collection (see also Bennett, Schneider, Arvanitakis, et al., 2012; Bennett, Schneider, Buchman, et al., 2012).

Personality

At study baseline (ROS: 1994; MAP: 2004), participants completed the Big Five personality inventory (NEO-FFI; Costa and McCrae, 1989). Participants were asked to rate the extent to which they agreed with a series of statements for each trait (e.g., I often feel tense and jittery), on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree). Item scores were summed for a total trait score (12 items per trait for neuroticism, openness, conscientiousness, and agreeableness, and 6 items for extraversion). ROS participants completed the full Big Five (neuroticism, extraversion, openness, conscientiousness, and agreeableness). MAP participants completed the questionnaire for neuroticism, extraversion, and conscientiousness only. All personality traits were *z*-standardized for use in analysis.

Covariates

Time between final cognitive assessment and death

Time between each participant's final cognitive assessment and death were calculated as date of death minus date of final cognitive assessment.

Demographics

Key demographics were entered into all analyses as covariates, specifically age at death (date of death minus date of birth), sex (1 = male, 0 = female), race (self-report, 0 = white; 1 = non-white [including black/African American, American Indian/Alaskan Native, Native Hawaiian/Pacific Islander, Asian, and other race]), early life SES (including paternal education, maternal education, and number of children in family [multiplied by −1]; indicators were *z*-scored, then averaged), and education (in years). Continuous demographic variables (age at death, early life SES, and education) were *z*-standardized for use in analysis.

Medical comorbidities

Key comorbidities (head trauma, hypertension, heart conditions, hypothyroidism, stroke, cancer, and diabetes) were assessed at baseline in both studies; each was rated as ever present (1), or absent (0) and summed to create a final score. The final score was *z*-standardized for use in analysis.

Cognitive activity

Cognitive activity was assessed at baseline in MAP only by asking participants to rate the typical time spent doing common activities in late life that involve intellectual processing: visiting a library, reading newspapers, reading magazines, reading books, writing letters, or playing games (e.g., checkers or other board games, cards, puzzles etc.). For these items, participants rated how often they engaged in these activities (1 = once a year; 2 = several times a year; 3 = several times a month; 4 = several times a week; 5 = every day/almost every day). These items were reverse coded for analysis so higher scores equaled higher engagement. Additionally, participants rated much time they spent reading per day (1 = none; 2 = <1 hr; 3 = 1 to <2 hr; 4 = 2 to <3 hr; 5 = ≥3 hr). This scale has been demonstrated to

have short-term temporal stability (r = .79; (Wilson et al., 2003), and adequate internal consistency (α = .71; Wilson et al., 2005). Responses were averaged into a composite measure of activity (Wilson et al., 2012). Cognitive activity was z-standardized for use in analysis.

APOE genotyping

Blood was collected with acid citrate dextrose anticoagulant and stored at room temperature. Lymphocyte separation was performed within 24 hr of collection. DNA was extracted from approximately 2–3 million cells, and genotyping was performed by an investigator blinded to all clinical and post-mortem data. APOE genotype was dichotomized by presence of e4 allele (0 = No; 1 = Yes).

Participants

Subjects from both ROS and MAP who had both pathology and global cognition scores were included in analyses; subjects were included in individual trait-based analyses if they had a score for that particular trait. Therefore, the total number of subjects contributing to each trait model may differ.

To address concerns regarding attrition of the MAP and ROS samples, we tested for differences in cognition, personality, and demographic variables between the subjects eliminated from and remaining in our analyses using t tests for continuous and chi-squared tests for categorical variables. Subjects dropped from our study were those missing cognition or pathology variables. These subjects were, on average, younger (88.3 vs 89.6 years of age date death), had fewer total comorbidities (1.9 vs 2.1), more highly educated, and had increased cognitive activity scores compared to those remaining in our analyses; however, the two samples did not differ in cognition or personality trait.

Data Analysis

The analysis plan for the current study was preregistered prior to analysis and can be found on OSF (https://osf.io/56c2b/registrations). Disclosures of knowledge of the data prior to analyses for the authors can be found in Table 1.

Descriptive statistics were calculated for all analysis variables before standardization, including means and standard deviations for continuous variables and frequencies for categorical variables. Correlations among each pathology types were calculated using Spearman's ρ. Simple bivariate regression models were run to evaluate the association between each pathology type and each personality trait. Our primary analysis followed the analytic methods of Negash et al. (2013). We used a two-step method to model the effect of personality on cognitive resilience. First, we modeled the effect of each pathology indicator and time between final cognitive assessment and death on subjects' final global cognition score using a multivariable linear regression model. We retained the residual value for each subject, which served as the key outcome variable of cognitive resilience, in which positive residual scores are an indicator of greater resilience. Next, we modeled the effect of personality trait on cognitive resilience using a series of linear regression models, first unadjusted, then adjusted for demographic characteristics (age at death, sex, race, early life SES, and education), then fully adjusted for demographic characteristics and additional covariates of APOE genotype, medical comorbidities, and cognitive activity. These models were run individually for reach of the five personality traits. Parameter estimates were generated using full-information maximum likelihood (FIML) so that all possible information was used to estimate the effects.

As an exploratory analysis, we also examined the effect of personality on "resilience to cognitive decline," defined as the difference (residual) in actual versus predicted cognitive change given the subject's level of pathology. To determine actual cognitive change, we retained the individual-level slope for each subject from a longitudinal, mixed effects model predicting cognition across time with random intercept and slope. These slopes represent the cognitive change for each individual subject. We then, following the same process as our primary analysis, modeled the effect of pathology and time between final cognitive assessment and death on final global cognition scores using multivariable linear regression, and retained the residual for each subject (resilience to cognitive decline). We then individually modeled the effect of each personality trait on resilience to cognitive decline, first unadjusted, then adjusted for demographic characteristics, then fully adjusted for all covariates. Parameter estimates were generated using FIML.

An additional exploratory analysis estimated the extent to which cognitive activity and education moderated the effect of personality traits on cognitive resilience. Interaction of cognitive activity and personality trait was included in each fully adjusted model from the primary analysis; a significant interaction of cognitive activity and personality would indicate moderation of cognitive activity on the relationship between personality and cognitive resilience. This process was repeated to assess the moderation effect of education. Due to oversaturation of the model using FIML, estimation of parameters for these exploratory analyses used maximum likelihood. Since cognitive activity was only included for the MAP sample, we did not include cognitive activity as a covariate in our models estimating education effects, to allow for inclusion of both ROS and MAP subjects in the final model.

Regression diagnostics were run for the linear regression of cognitive resilience and resilience to cognitive decline on pathology. Those with Cook's $D > 4/n$ were identified as potential outliers. As a sensitivity analysis, these records were removed, analyses were re-run, and model results were compared across both samples. Results remained the same across both samples, and so results from the models

Table 1. Disclosures

	Yes	No
Can you document (with data contract or something similar) that all team members have never had any exposure to the data before the preregistration was created?		X
Do you assert, even if no verifiable evidence exists, that all team members have never had any exposure to the data before the preregistration was created?		X
Do you assert that the author of the preregistration document did not have any exposure to the data before the preregistration, even if some co-authors have worked with the data?	X	
Do you assert that the authors of the paper have had no exposure to the primary variables (including calculating descriptive statistics) in the analyses, even if they have worked with other variables from the same sample?		X
Do you assert that the authors of the paper have had no exposure to one or more primary variables (including calculating descriptive statistics), even if they have worked with some of the primary variables?		X
Do you assert that the authors of the paper have had exposure to all the primary variables, but that they have never done any analyses that examined their associations?	X	
Does the primary analysis involve data from new waves of assessment that have never been analyzed (even if similar variables from prior waves had been examined by study authors)?	X	
Have authors had exposure to variables in the same dataset that might be expected to correlate relatively strongly with those used in the primary analysis for this paper (e.g., depression and loneliness; self-esteem and life satisfaction)?	X	
Are you analyzing data from a subset of participants (e.g., a hold-out sample) who you have not studied before?		X

including all cases are shown below. All parameters estimates are presented with standard errors and 95% confidence intervals. All analyses were completed using SAS version 9.4. Annotated scripts and outputs for all analyses are available on OSF (https://osf.io/56c2b/). The data used for this analysis can be requested through the RADC Hub (https://www.radc.rush.edu).

Results

Of the 857 MAP and 783 ROS subjects who have been autopsied, 756 (88%) and 619 (79%), respectively, had both cognition and pathology data and at least one measurement of personality traits, and so were included in our study. Table 2 summarizes the descriptive statistics of our sample. Two-thirds of the participants were male, 97% were white, and the average age at death was 90 years. Cognition was assessed for an average of 8.14 years (range: 0.05–24.45). The average time between final cognitive assessment and death was 0.89 years, and ranged from less than 1 day to 13 years. On average, subjects reported high levels of agreeableness (mean = 33.97, *SD* = 3.83, range = 20–48) and conscientiousness (mean = 33.25, *SD* = 5.36, range = 11–48), and relatively low neuroticism (mean=16.46, *SD* = 6.30, range = 0–42).

Cognitive Resilience

On average, pathology types, with the exception of beta-amyloid and PHF tau tangles, were not significantly correlated with each other. Beta-amyloid load and PHF tau tangles were the most highly correlated pair (ρ = 0.48). Seventy-three percent of the pairs had correlations less than 0.1. Supplementary Table S1 shows the associations of neuropathological markers with cognitive level and change after adjusting for the time between the last assessment and death. In a single model, beta-amyloid load, tangle density, having one or more gross chronic infarctions, atherosclerosis, Lewy bodies in neocortex, TDP-43, and hippocampal sclerosis all had significant negative associations with cognition. Similarly, beta-amyloid load, tangle density, having one or more gross chronic infarctions, atherosclerosis, Lewy bodies in neocortex, hippocampal sclerosis, and arteriolosclerosis all had negative associations with cognitive change. In bivariate analyses, beta-amyloid load was positively associated with neuroticism and negatively associated with conscientiousness, and tangle density was positively associated with both neuroticism and extraversion. Having one or more micro-infarctions was associated with lower levels of openness, and neo-cortical Lewy bodies were associated with higher levels of openness. Atherosclerosis was negatively associated with agreeableness. These results can be found in Supplementary Table 1.

We quantified cognitive resilience continuously, in which resilience represented the difference between predicted

Table 2. Descriptive Statistics

	Mean/*n*	*SD*/%	Min–Max
Age at death (years)	89.57	6.55	65.90–108.28
Gender (male)	441	32.1%	0–1
Education (years)	16.18	3.65	3–30
Race (white)	1331	96.9%	0–1
Early life SES	−0.05	0.72	−2.73 to 2.17
Medical comorbidity count	2.13	1.26	0–6
Past cognitive activity	3.19	0.78	1–5
APOE present	336	24.8%	0–1
Time from final cog to death (years)	0.89	1.21	0.002–13.17
Time from personality assess to death (years)	9.03	5.32	0.05–24.45
Length of cognition assessment (years)	8.14	5.32	0–23.98
Neuroticism	16.64	6.30	0–42
Extraversion	15.14	3.08	6–24
Openness	25.77	5.09	4–41
Conscientiousness	33.25	5.36	11–48
Agreeableness	33.97	3.83	20–48

Note: SES = socioeconomic status.

and actual cognition, given a subject's level of pathology. Supplementary Figure S1 shows the relationship between predicted and actual cognition. Higher actual versus predicted cognition (i.e., positive residuals) indicate a higher resilience; higher predicted versus actual cognition (i.e., negative residuals) indicate lower resilience. Similarly, resilience to cognitive decline was quantified, continuously, as the difference between predicted and actual cognitive change over time (i.e., cognitive slope), given a subject's level of pathology. The relationship between predicted and actual cognition is shown in Supplementary Figure S2, in which lower actual versus predicted cognitive slope indicates a subject with higher resilience to cognitive decline, and lower predicted versus actual cognitive slope indicates a subject with lower resilience to cognitive decline.

Personality and Cognitive Resilience

Table 3 shows the association of personality with cognitive resilience (neuroticism, extraversion, and conscientiousness: N = 1,375; openness and agreeableness: N = 619 [ROS only]). In the unadjusted model, neuroticism was negatively associated with cognitive resilience (estimate = −0.11; 95% CI: −0.17, −0.05). In the partially adjusted model, the association of neuroticism was similar (estimate = −0.10; 95% CI: −0.16, −0.04). Finally, in the fully adjusted model, the negative associations of neuroticism with cognitive resilience remained significant (estimate = −0.10; 95% CI: −0.15, −0.04). Some covariates were associated with resilience: age at death, SES, medical comorbidities, and cognitive activity; estimates of these effects for the neuroticism model are shown in Table 3, and effects were similar across each trait model (see here https://osf.io/56c2b/). Openness was positively associated with cognitive resilience (estimate = 0.04; 95% CI: 0.01, 0.19) in the unadjusted model, but once adjusted for covariates, this association was no longer significant. In their respective models, extraversion, conscientiousness, and agreeableness had positive associations with cognitive resilience; however, these associations were also not significant in any of the models.

Exploratory Analyses

Personality and resilience to cognitive decline

Table 4 shows the effects of personality on resilience to cognitive decline (neuroticism, extraversion, and conscientiousness: N = 1,375; openness and agreeableness: N = 619 (ROS only). In the unadjusted model, neuroticism was negatively associated with resilience to cognitive decline (estimate = −0.06; 95% CI: −0.12, −0.01). However, in the partially adjusted model and fully adjusted model, the association of neuroticism was no longer significant (estimate = −0.05; CI: −0.11, 0.01) in both models. In the unadjusted model, conscientiousness had a positive association with resilience to cognitive decline (estimate = 0.08; 95% CI: 0.02, 0.15). This association held after adjusting for demographic characteristics (estimate = 0.09; CI: 0.03, 0.16), and in the fully adjusted model (0.09; 95% CI: 0.02, 0.16). In their respective models, extraversion, openness, and agreeableness were not associated with resilience to cognitive decline. Covariate associations were similar across all and were significant for age, sex, medical comorbidities, and cognitive activity; estimates of these effects for the neuroticism model are shown in Table 4, and effects were similar across each trait model.

Table 3. Personality and Cognitive Resilience, Model Summary

	Model 1		Model 2		Model 3	
	Estimate (*SE*)	95% CI	Estimate (*SE*)	95% CI	Estimate (*SE*)	95% CI
Neuroticism	−0.11 (0.03)	−0.17, −0.05	−0.10 (0.03)	−0.16, −0.04	−0.10 (0.03)	−0.15, −0.04
Age at death					−0.09 (0.03)	−0.14, −0.03
Male gender					0.04 (0.06)	−0.07, 0.15
Non-white					−0.24 (0.16)	−0.56, 0.07
SES					0.12 (0.04)	0.04, 0.19
Education					−0.02 (0.03)	−0.09, 0.04
APOE genotype					−0.02 (0.06)	−0.15, 0.10
Comorbidity count					0.05 (0.03)	0.004, 0.11
Cognitive activity					0.15 (0.04)	0.08, 0.22
Extraversion	0.03 (0.03)	−0.03, 0.08	0.03 (0.03)	−0.02, 0.08	0.02 (0.03)	−0.04, 0.07
Conscientiousness	0.04 (0.03)	−0.03, 0.10	0.04 (0.03)	−0.02, 0.11	0.02 (0.03)	−0.05, 0.09
Openness (ROS)	0.10 (0.04)	0.01, 0.19	0.06 (0.05)	−0.03, 0.16	0.06 (0.05)	−0.03, 0.15
Agreeableness (ROS)	0.01 (0.04)	−0.08, 0.10	0.01 (0.04)	−0.08, 0.10	0.02 (0.04)	−0.07, 0.10

Note: ROS = Religious Orders Study; SES = socioeconomic status. Model 1 = unadjusted; Model 2 = adjusted for demographics; Model 3 = adjusted for demographics, APOE, comorbidities, and cognitive activities.

Table 4. Personality and Cognitive Change Resilience, Model Summary

	Model 1		Model 2		Model 3	
	Estimate (*SE*)	95% CI	Estimate (*SE*)	95% CI	Estimate (*SE*)	95% CI
Neuroticism	−0.06 (0.03)	−0.12, −0.01	−0.05 (0.03)	−0.11, 0.01	−0.05 (0.03)	−0.11, 0.01
Age at death					0.09 (0.03)	0.04, 0.15
Male gender					0.18 (0.06)	0.06, 0.30
Non-white					0.18 (0.19)	−0.13, 0.49
SES					0.03 (0.04)	−0.05, 0.11
Education					−0.01 (0.03)	−0.07, 0.05
APOE genotype					−0.07 (0.06)	−0.19, 0.06
Comorbidity count					0.09 (0.03)	0.03, 0.14
Cognitive activity					0.10 (0.04)	0.03, 0.17
Extraversion	0.01 (0.03)	−0.04, 0.07	0.02 (0.03)	−0.04, 0.07	0.01 (0.03)	−0.05, 0.06
Conscientiousness	0.08 (0.03)	0.02, 0.15	0.09 (0.03)	0.03, 0.16	0.09 (0.04)	0.02, 0.16
Openness (ROS)	0.05 (0.04	−0.04, 0.14	0.08 (0.05)	−0.02, 0.17	0.07 (0.05)	−0.03, 0.16
Agreeableness (ROS)	0.01 (0.04)	−0.07, 0.10	0.03 (0.04)	−0.06, 0.11	0.04 (0.04)	−0.05, 0.13

Note: ROS = Religious Orders Study; SES = socioeconomic status. Model 1 = unadjusted. Model 2 = adjusted for demographics. Model 3 = adjusted for demographics, APOE, comorbidities, and cognitive activities.

Personality and resilience, moderated by cognitive activities

As stated above, cognitive activity was positively associated with cognitive resilience in the fully adjusted neuroticism and extraversion models. In this exploratory analysis, we examined the effect that cognitive activities may have on the relationship between personality and resilience. The cognitive activity model in Table 5 shows the associations of personality trait, cognitive activity, and the moderation effect of cognitive activity × trait (neuroticism: n = 569; extraversion: n = 674; conscientiousness: n = 326 [MAP only]). While neuroticism and cognitive activity remained associated with cognitive resilience, the association of neuroticism on cognitive resilience was not moderated by cognitive activity (effect = 0.06; 95% CI: −0.01, 0.13). Similarly, the association of extraversion on resilience was not modified by cognitive activity (estimate = 0.01; 95% CI: −0.05, 0.08). In the conscientiousness model, the association between cognitive activity and resilience was much weaker (estimate = 0.11; 95% CI: −0.01, 0.23), and the interaction suggested that there was no moderating effect of cognitive activity on the conscientiousness/resilience association (estimate = −0.04; 95% CI: −0.15, 0.07). Note that cognitive activity was only captured for MAP participants, and so we were not able to measure the moderation effect of cognitive abilities on the effect of openness or agreeableness on cognitive resilience.

Personality and resilience, moderated by education

In fully adjusted analyses, education was not found to have an association with cognitive resilience in any model; however, in this exploratory analysis, we examined the potential moderation effect education may have on the relationship between traits and cognitive resilience. In the education model in Table 5, we present the estimates of trait, education, and the moderation effect of Education * Trait (adjusted for covariates) (neuroticism: N = 1,170; extraversion: N = 1,275; conscientiousness: N = 927; openness: N = 597 [ROS only]; agreeableness: N = 598 [ROS only]). Neuroticism remained associated with cognitive resilience; however, this association was not moderated by education (estimate = −0.02; 95% CI: −0.17, 0.05). Additionally, we found no association of extraversion, conscientiousness, openness, agreeableness, education, or any moderation effect of education on trait in the extraversion and conscientiousness moderation models. Note that these fully adjusted models did not include the covariate of cognitive activities, as this was only assessed in MAP participants.

Table 5. Personality and Cognitive Resilience, Moderated by Cognitive Activity and Education

	Cognitive activity model		Education model	
	Estimate (*SE*)	95% CI	Estimate (*SE*)	95% CI
Neuroticism	−0.09 (0.04)	−0.16, −0.02	−0.11 (0.03)	−0.17, −0.05
Cognitive activities [a]	0.12 (0.04)	0.03, 0.2	NA	NA
Education	0.06 (0.06)	−0.06, 0.17	0.01 (0.03)	−0.05, 0.07
Cognitive activity × Neuroticism	0.06 (0.04)	−0.01, 0.13	NA	NA
Education × Neuroticism	NA	NA	−0.02 (0.03)	−0.08, 0.04
Extraversion	0.02 (0.04)	−0.05, 0.09	0.04 (0.03)	−0.01, 0.10
Cognitive activities [a]	0.15 (0.04)	0.08, 0.22	NA	NA
Education	0.07 (0.05)	−0.03, 0.18	0.03 (0.03)	−0.03, 0.08
Cognitive activity × Extraversion	0.01 (0.03)	−0.05, 0.08	NA	NA
Education × Extraversion	NA	NA	0.01 (0.03)	−0.05, 0.07
Conscientiousness	0.02 (0.05)	−0.08, 0.11	0.03 (0.04)	−0.04, 0.10
Cognitive activities [a]	0.11 (0.06)	−0.01, 0.23	NA	NA
Education	0.15 (0.07)	0.01, 0.3	0.02 (0.04)	−0.05, 0.09
Cognitive activity × Conscientiousness	−0.04 (0.06)	−0.15, 0.07	NA	NA
Education × Conscientiousness	NA	NA	0.06 (0.03)	−0.01, 0.13
Openness [b]			0.08 (0.05)	−0.03, 0.18
Education			0.07 (0.05)	−0.03, 0.17
Openness × Education			−0.04 (0.05)	−0.14, 0.05
Agreeableness [b]			0.08 (0.05)	−0.03, 0.18
Education			0.07 (0.05)	−0.03, 017
Agreeableness × Education			−0.07 (0.05)	−0.16, 0.03

Notes: Cognitive activity model = includes cognitive activities and moderation effect of Cognitive activities × Trait, adjusted for age, gender, race, socioeconomic status (SES), education, APOE, and comorbidities. Education model = includes education and moderation effect of Education × Trait, adjusted for age, gender, race, SES, APOE, and comorbidities.

[a]Education model was not adjusted for cognitive activities, as this variable was not available for ROS subjects. [b]Openness and agreeableness were only assessed in Religious Orders Study (ROS) subjects.

Discussion

There is growing interest in the discordances between neurological pathology and symptoms of dementia. Who are these individuals who are effectively able to forestall the progression of cognitive decline in the face of growing pathology? Using the residualized approach established by Negash et al. (2013) for modeling cognitive resilience, we examined the extent of associations between personality traits and resilience to pathology. We also explored whether these associations were moderated by education and cognitive activity.

Summary and Interpretation of Findings

Our key predicted finding was the association between neuroticism and cognitive resilience. Low neuroticism was associated with greater resilience to pathology, meaning that individuals lower on this trait had better cognitive performance relative to their level of pathology. This suggests that individuals with low neuroticism (meaning they are typically less anxious, report less depression, less vulnerability, less anger) may have greater brain reserve capacity, which means a better ability to compensate and maintain cognitive functioning in the face of accruing pathology, stroke (macro- or microinfarcts), brain injuries, or other factors that may place downward pressure on cognitive functioning (Bennett, 2017; Opdebeeck et al., 2016; Stern, 2012). Further, the fact that we found an association for neuroticism only in the models that considered cognitive functioning at the final assessment, and not in the models that considered multi-year cognitive slopes suggests that the effect of neuroticism on cognitive reserve may be limited to terminal cognitive function, and not longitudinal change. It is possible that individuals higher in neuroticism died sooner (Graham et al., 2017; Turiano et al., in press) and thus had less cognitive change data to reliably test resilience to cognitive change. Additionally, this result could also be a reflection of end-of-life increases in neuroticism (Graham et al., 2020), although the data sets in the current study did not contain sufficient personality data to test this.

Our analyses for cognitive change were exploratory, and we found that individuals higher in conscientiousness experienced less cognitive decline relative to their level of pathology. This idea that some individuals experience a flatter trajectory than expected given their pathology is consistent with the cognitive reserve hypothesis (Stern, 2012), and supported by prior work finding that, compared to individuals with clinical dementia, individuals who are asymptomatic tend to be higher in conscientiousness and lower in neuroticism (Terracciano et al., 2013). Further, the fact that we found an association for conscientiousness only in the models that considered cognitive change, and not in the models that only considered cognition at the final assessment, suggests that the effect of conscientiousness on cognitive reserve may be extended to cognitive change over the course of older adulthood. A highly conscientious individual is likely motivated to continually work to maintain cognitive function over the full course of their older adulthood. It is possible that the protective effects of conscientiousness that were found in the current study may ameliorate the negative association for neuroticism. A next logical step in further interrogating the associations among conscientiousness, neuroticism, and cognitive resilience would be to test the notion of healthy neuroticism. Prior work has operationalized healthy neuroticism as the interaction between neuroticism and conscientiousness, and has found robust evidence for an association with health behaviors (smoking and physical activity) (Graham et al., in press), but not for the presence or onset of chronic conditions (heart conditions, diabetes, hypertension) (Weston et al., in press) or mortality (Turiano et al., in press). We urge future researchers to examine the association between healthy neuroticism and cognitive resilience, possibly using multiple alternative definitions of healthy neuroticism (e.g., interactions between neuroticism on the one hand, and conscientiousness or self-rated health on the other).

Overall, these findings lend credence to the idea that personality has a pathoplastic effect on neuropathology (Segerstrom, 2018), such that certain traits are associated with better cognitive levels (for low neuroticism) and less decline (for high conscientiousness) despite neuropathologic burden. Lastly, the null findings for extraversion and agreeableness were expected, given the literature showing a lack of consistent findings for these two traits. However, the null effect for openness was not consistent with our hypotheses. When openness was in the models without demographic covariates, there was an association for openness that was consistent with our hypothesis, suggesting that openness may be associated with greater cognitive resilience. This effect was no longer significant after demographics were accounted for. This is somewhat surprising considering that associations among openness and cognitive outcomes in the literature are often robust to covariate adjustment. Our inclusion of covariates was fairly comprehensive, in order to account for possible confounds with pathology, and thus these additional controls may have accounted for the variance that openness otherwise would have. Additionally, all bodies of literature are subject to publication bias and file-drawer effects, so it is likely that null effects for openness are under-reported.

We did not have hypotheses to specify our expectations regarding the possible moderating role that education or cognitive activity would play in the personality resilience associations. The lack of evidence found in the current study suggests that the associations among personality traits and cognitive resilience are independent of levels of education or activity. Personality has a unique association with cognitive resilience, and the conditions under which this relationship is strongest (or the underlying mechanisms explaining this relationship) were not detected here. In addition to the cognitive reserve hypothesis (Stern, 2012),

another framework through which we could interpret these findings is the health behavior model. This model posits that the mechanism through which personality influences health outcomes in older adulthood (including cognitive health) is behavioral. Individuals high in certain traits (e.g., conscientiousness) are more likely to engage in healthy behaviors throughout their lives that may help protect them from many of the diseases of old age, including chronic conditions, cognitive decline/dementia, and declining mental health. For example, highly conscientious individuals may be more likely to attend closely to their own changing cognitive function, work to discover ways to maintain their abilities, and be motivated towards engaging in stimulating activities that will allow them to tolerate pathology without showing signs of cognitive decline. In other words, perhaps certain personality traits predispose individuals to the development of neuropathologies and resilience to them via behavioral pathways.

We can also interpret the present findings in light of Baltes' model of Selection, Optimization, and Compensation (Baltes, 1997). This theory suggests that as older adults experience loss (emotional, physical, social, cognitive), they focus their priorities on things that matter most to them (selection), prioritize their efforts onto those things so they are maximized (optimization), and work towards compensating for those things that are lost. It is assumed that this process occurs somewhat explicitly, and deliberately. But on the cognitive level, it could be occurring in subtle ways that are taking place without an individual's awareness. As pathology grows in the brain, individuals with greater cognitive reserve may be better equipped to select for what is most important in terms of maintaining cognitive function, optimizing what is absolutely necessary, and effectively compensating for what they are losing. High conscientiousness (motivation, organization, deliberation, competence, discipline) may help an individual be effective at this process, while high neuroticism (anxiety, malcontent, depression, instability) may impede them. More research is needed in order to understand these possible mechanisms more deeply.

Limitations and Constraints on Generality

The current study was limited to the data available. The personality measures used were self-report. Cognitive assessments are always limited by the possibility of recall and testing effects. These data, and many of the other existing longitudinal datasets typically used in aging research, are characteristically WEIRD (White, Educated, Industrialized, Rich, and Democratic) (Henrich et al., 2010). The ROS and MAP samples in particular have a very low proportion of minority participants, have generally high education, and tend to have very high longevity. As such, we cannot be confident that these results would generalize to less-industrialized non-western cultures, or to all American older adults. Also, since cognitive activity was only assessed in the MAP study, we could not model activity and education in the same analysis. Future studies with both measures should give further consideration to the roles that these factors play uniquely and together. Further, medical comorbidities were only adjusted from their baseline assessment. It is possible that the onset of these conditions over the course of the study (over and above baseline presence) could have a unique influence on the resilience outcome. Additionally, using a self-report assessment of cognitive activity is limiting, as response bias, specifically demand characteristics and social desirability may influence reliability. This may have contributed to the lack of associations found for cognitive activity, and future studies should study this using alternative data collection methods (e.g., informant reports). Future studies should take a closer look at the presence and development of age-related conditions and their independent associations with cognitive resilience. The first priority of future studies should be to replicate these findings in other, more diverse, datasets. Additionally, work should be done to understand mechanisms explaining the associations between personality and cognitive resilience, as well as exploring these associations within individual cognitive domains, to understand whether resilience to pathology is robust to specific domains of cognition.

Conclusion

Certain personality traits are associated with cognitive resilience, and personality can help to explain variation in cognitive performance beyond what is predicted by level of neuropathology. Individuals with higher levels of neuroticism display less cognitive resilience at the end of life (i.e., greater vulnerability). Exploratory analyses suggest that individuals who are higher in conscientiousness display more cognitive resilience when considering longitudinal change in cognitive functioning. These associations are not fully explained by differences in SES or cognitive activity, though more research is necessary to better understand the mechanisms of these associations.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

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Conflict of Interest

None declared.

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