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Prog Neuropsychopharmacol Biol Psychiatry. Author manuscript; available in PMC 2021 June 08.

Published in final edited form as:

Prog Neuropsychopharmacol Biol Psychiatry. 2020 June 08; 100: 109912. doi:10.1016/j.pnpbp.2020.109912.

Vitamin D Polygenic Score is associated with Neuroticism and the General Psychopathology Factor

Reut Avinun[1,2], **Adrienne L. Romer**[1,3,4], **Salomon Israel**[2,5]

[1]Laboratory of NeuroGenetics, Department of Psychology & Neuroscience, Duke University, Durham, NC, USA

[2]Department of Psychology, The Hebrew University of Jerusalem, Jerusalem, Israel

[3]Center for Depression, Anxiety and Stress Research, McLean Hospital, Belmont, MA, USA

[4]Department of Psychiatry, Harvard Medical School, Boston, MA, USA.

[5]Scheinfeld Center of Human Genetics for the Social Sciences, The Hebrew University of Jerusalem, Jerusalem, Israel

Abstract

Vitamin D, used here to refer to both 25-hydroxyvitamin D, the main circulating form of the vitamin, and 1,25-hydroxyvitamin D, the biologically active form, has been shown to influence brain development and function. Consistent with these findings, low levels of vitamin D have been implicated in various mental disorders, including depression, schizophrenia, and autism. Recently, a shared variance across multiple categories of mental health disorders has been identified and shown to be genetically influenced. This shared variance, thought to represent a general risk for psychopathology, has been termed the p factor. Individuals with high p factor scores are characterized by high neuroticism and low agreeableness and conscientiousness. Here, we investigated the links between vitamin D polygenic scores — derived from the latest genome-wide association study of circulating vitamin D (25-hydroxyvitamin D) levels — the Big Five personality traits (neuroticism, agreeableness, conscientiousness, openness-to-experience, and extraversion), and the p factor, in a sample of 522 (278 women, mean age 20±1 years) non-Hispanic Caucasians. Vitamin D polygenic scores were significantly and negatively associated with neuroticism and the p factor, even after correcting for multiple comparisons, and controlling for sex, age, ancestry, socioeconomic status, and body mass index. Based on previous research

Corresponding Author: Reut Avinun, Ph.D., Department of Psychology, The Hebrew University of Jerusalem, Mount Scopus, Jerusalem, 91905 Israel. reut.avinun@mail.huji.ac.il

CRediT authorship contribution statement

Reut Avinun: Conceptualization, Formal Analysis, and Writing - Original draft preparation; **Adrienne L. Romer:** Formal Analysis and Writing-Reviewing and Editing; **Salomon Israel**: Conceptualization and Writing- Reviewing and Editing.

Conflict of Interest

The authors declares no conflict of interest.

Ethical statement

We report that our manuscript meets the guidelines for ethical conduct and report of research. All procedures were approved by the Institutional Review Board of the Duke University Medical Center, and participants provided informed consent before study initiation.

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implicating neuroticism as a risk factor for psychopathology, mediation was tested. Results showed a significant indirect effect from the vitamin D polygenic score to the p factor via neuroticism. Our findings support a genetic link between vitamin D levels, neuroticism, and the p factor, but due to the cross-sectional nature of our data, future studies are needed to clarify the causal associations between these phenotypes.

Keywords

General psychopathology factor; the p factor; vitamin D; neuroticism; personality; cross-disorder

1. Introduction

Vitamin D, used here to refer to both 25-hydroxyvitamin D, the main circulating form of the vitamin and the form usually measured to assess vitamin D status, and 1,25-hydroxyvitamin D, the biologically active form, which is created by hydroxylation of 25-hydroxyvitamin D, is a potent fat-soluble vitamin that affects many physiological functions. It has two known receptors: the vitamin D receptor, which is a nuclear receptor that can affect transcription, and PDIA3 (protein disulfde isomerase family member3), which is a membrane receptor. Enzymes involved in its synthesis and degradation, and the two vitamin D receptors have been found in the brain (Cui et al., 2013; El-Atifi, Dreyfus, Berger, & Wion, 2015; Eyles, Smith, Kinobe, Hewison, & McGrath, 2005; Landel, Stephan, Cui, Eyles, & Feron, 2018), suggesting a possible role for vitamin D in brain function.

In vitro studies and animal studies have shown vitamin D affects the development of dopaminergic neurons, regulates dopamine and serotonin related genes, and affects the tonic and phasic release of dopamine (Cui, Gooch, Petty, McGrath, & Eyles, 2017). Additionally, vitamin D levels have been shown to modulate inflammation, affect the proliferation and differentiation of neural stem cells, and regulate calcium channels that are essential for neurotransmission (Cui et al., 2017). Consistent with the involvement of these processes in mood and psychopathology (e.g., Friedrich, 2014; Grace, 2016; Lesch & Waider, 2012), low levels of vitamin D, a prevalent condition worldwide (Cashman, 2019; Palacios & Gonzalez, 2014), have been associated with several mental disorders, including depression (Grudet et al., 2020; Parker, Brotchie, & Graham, 2017), externalizing problems (Robinson et al., 2020), schizophrenia (Eyles et al., 2018), autism (Vinkhuyzen et al., 2018), and obsessive compulsive disorder (Yazici, Percinel Yazici, & Ustundag, 2018).

Mendelian randomization (Davies, Holmes, & Smith, 2018) is an analytical method that relies on the random assortment of genetic variants to determine whether there is a causal relationship between a hypothesized risk factor and an outcome, while minimizing the risk of confounding and reverse causality. Mendelian randomization studies that tested the relationship between vitamin D and depression (Meng et al., 2019; Michaëlsson, Melhus, & Larsson, 2018; Milaneschi et al., 2019) or vitamin D and schizophrenia (Taylor et al., 2016), did not find evidence for a causal effect of vitamin D on these disorders. However, Mendelian randomization is limited in several ways (Allman, Aban, Tiwari, & Cutter, 2018). For example, a key requirement of the method is to avoid pleiotropy, consequently usually

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only very few single nucleotide polymorphisms are used, which only explain a small proportion of the variance (i.e., <2%). In the case of highly heterogeneous mental disorders, such as depression, this may lead to a lack of statistical power. Importantly, a meta-analysis of randomized controlled trials (Spedding, 2014), which tested the effect of vitamin D supplementation on depression, did find an effect after excluding papers with flaws (i.e., studies that did not measure vitamin D circulating levels, included participants without vitamin D deficiency, or did not show an improvement in vitamin D status after the intervention).

As the possible involvement of vitamin D in various mental disorders suggests, comorbidity is prevalent. About 40% of the individuals with one class of disorders (e.g., mood, anxiety, substance abuse) are likely to be diagnosed with another (Merikangas et al., 2010; Newman, Moffitt, Caspi, & Silva, 1998). Consequently, mental disorder categories tend to correlate and contribute to higher order latent factors, including externalizing, internalizing and thought disorders. These higher-order psychopathology dimensions have also been found to correlate (Wright et al., 2013) and can be captured by a general psychopathology factor (Lahey et al., 2012), often called the *p factor* (Caspi et al., 2014). Put differently, the p factor captures shared variation and comorbidity across diagnostic categories, and it is thought to represent a general liability for mental disorder, as well as its persistence and severity (Caspi & Moffitt, 2018). It has been identified in diverse samples (Caspi & Moffitt, 2018; Lahey, Krueger, Rathouz, Waldman, & Zald, 2017) and shown to have a genetic component (Lee et al., 2019; Selzam, Coleman, Caspi, Moffitt, & Plomin, 2018).

The p factor has also been found to highly correlate with a specific personality profile of high levels of neuroticism and low levels of agreeableness and conscientiousness (Caspi et al., 2014). These three personality traits are components of a relatively consistent five factor model, which also includes the higher-order dimensions of extraversion and openness-to-experience. Each of these so-called Big Five personality traits captures a wide array of feelings, thoughts, and behaviors (Digman, 1990). Only one previous study (Ubbenhorst, Striebich, Lang, & Lang, 2011) has examined the correlations between circulating vitamin D levels and the Big Five. In a sample of 206 participants, Ubbenhorst et al., observed the following correlations: r=0.17 with extraversion, r=0.15 with openness-to-experience, r=0.09 with neuroticism, r=0.08 with conscientiousness, and r=0.04 with agreeableness. Of these, extraversion and openness-to-experience were significant.

Given that low vitamin D levels have been implicated in multiple mental disorder categories and that the Big Five personality traits have been associated with the p factor and with vitamin D levels, in the current study, we explored the possible links between polygenic scores for vitamin D serum concentrations (25-hydroxyvitamin D), the Big Five personality traits, and the p factor, in a sample of 522 young adults. The vitamin D polygenic scores were derived from a recent genome-wide association study (GWAS) of 79,366 individuals of European descent (Jiang et al., 2018), in which nominally significant ($p \leq .05$) single nucleotide polymorphisms (SNPs) explained about 6% of the variance in circulating vitamin D levels.

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2. Methods

2.1. Participants

Our discovery sample consisted of 522 self-reported non-Hispanic Caucasian participants (278 women, mean age 19.79±1.24 years) from the Duke Neurogenetics Study (DNS). Participants were recruited through posted flyers on the Duke University campus and through a Duke University listserv. All procedures were approved by the Institutional Review Board of the Duke University Medical Center, and participants provided informed consent before study initiation. All participants were free of the following study exclusions: 1) medical diagnoses of cancer, stroke, diabetes requiring insulin treatment, chronic kidney or liver disease, or lifetime history of psychotic symptoms; 2) use of psychotropic, glucocorticoid, or hypolipidemic medication; and 3) conditions affecting cerebral blood flow and metabolism (e.g., hypertension).

2.2. Race/Ethnicity

Because self-reported race and ethnicity are not always an accurate reflection of genetic ancestry, an analysis of identity by state of whole-genome SNPs in the DNS was performed in PLINK v1.90 (Purcell et al., 2007). Before running the multidimensional scaling (MDS) components analysis (Price et al., 2006), SNPs were pruned for high LD (r^2>0.1), C/G and A/T SNPs were removed, SNPs with a missing rate >.05 or a minor allele frequency <.01 were removed, SNPs that did not pass the Hardy-Weinberg equilibrium test (p<1e-6) were removed, sex chromosomes were removed, and regions with long range LD were removed (the MHC and 23 additional regions; Price et al., 2008). The non-Hispanic Caucasian subgroup was determined by both self-reports (i.e., Please indicate your race: 1-Caucasian/White, 2-African American/Black, 3-Asian, 4-American Indian, 5-Bi- or multiracial, 6-Other) and the multidimensional scaling components of the entire mixed ancestry DNS sample. The first two MDS components computed for the non-Hispanic Caucasian subsample were used as covariates to control for ancestry. The decision to use only the first two components was based on an examination of a scree plot of the variance explained by each component. Relevant plots are available at https://www.haririlab.com/methods/genetics_QCplots.html.

2.3. Socioeconomic status

SES was used as a covariate in the analyses due to its association with vitamin D levels (Forrest & Stuhldreher, 2011) and mental disorders such as depression (Avinun, 2019). SES was assessed using the “social ladder” instrument (Adler, Epel, Castellazzo, & Ickovics, 2000), which asks participants to rank themselves relative to other people in the United States (or their origin country) on a scale from 0–10, with people who are best off in terms of money, education, and respected jobs, at the top (a score of 10) and people who are worst off at the bottom (a score of 0).

2.4. Body Mass Index (BMI)

BMI was used as a covariate in the analyses due to its association with vitamin D levels (Forrest & Stuhldreher, 2011) and mental disorders such as depression (Avinun & Hariri,

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2019). BMI was calculated based on the height and weight of the participants ((pounds/inches^2)*703).

2.5. The General Psychopathology factor (p factor)

Current and lifetime DSM-IV Axis I or select Axis II disorders (antisocial personality disorder and borderline personality disorder), were assessed with the electronic Mini International Neuropsychiatric Interview (e-M.I.N.I.; Sheehan et al., 1998) and Structured Clinical Interview for the DSM-IV Axis II subtests (First, Gibbon, Spitzer, Williams, & Benjamin, 1997). Clinical psychologists, graduate students, and post-baccalaureate research assistants under the supervision of a licensed clinical psychologist conducted interviews. Of the 522 non-Hispanic Caucasians included in our analyses, 117 individuals had at least one DSM-IV diagnosis, including 66 with alcohol use disorders, 19 with non-alcohol substance use disorders, 28 with major depressive disorders, 16 with bipolar disorders, 14 with panic disorder (no agoraphobia), 12 with panic disorder including agoraphobia, five with social anxiety disorder, 10 with generalized anxiety disorder, five with obsessive compulsive disorder, and three with eating disorders.

Previously (Romer et al., 2018), our group generated p factor scores for the entire DNS sample (N=1386) using confirmatory factor analyses of self-report questionnaires and the e-M.I.N.I. measures of internalizing, externalizing, and thought disorder symptoms. All confirmatory factor analyses were performed in Mplus version 7.4 (Muthén & Muthén, 2007) using the weighted least squares means and variance adjusted (WLSMV) algorithm. The WLSMV estimator is appropriate for categorical and nonmultivariate normal data and provides consistent estimates when data are missing at random with respect to covariates (Asparouhov & Muthén, 2010). The generated p factor scores were standardized to a mean of 100 (SD = 15), with higher scores indicating a greater propensity to experience all forms of psychiatric symptoms. More details regarding the calculation of the p factor scores can be found in the Supplemental material.

2.6. Personality

The NEO personality inventory revised (NEO-PI-R; Costa & McCrae, 1995), which includes 240 items, was used to assess neuroticism (based on the anxiety, angry/hostility, depression, self-consciousness, impulsiveness, and vulnerability facets), agreeableness (based on the trust, straightforwardness, altruism, compliance, modesty, and tender-mindedness facets), conscientiousness (based on the competence, order, dutifulness, achievement striving, self-discipline and deliberation facets) extraversion (based on the warmth, gregariousness, assertiveness, activity, excitement-seeking, and positive emotions facets), and openness-to-experience (based on the fantasy, aesthetics, feelings, actions, ideas, and values facets). Each facet was a sum of 8 items, and each personality trait was a sum of the facets (some items were reverse coded as indicated). Participants rated the 240 items on a scale ranging from (0) *strongly disagree* to (4) *strongly agree.* Internal consistency of the Big Five was assessed by Cronbach's alpha as acceptable to good and ranged between 0.72 to 0.84.

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2.7. Genotyping

In the DNS, DNA was isolated from saliva using Oragene DNA self-collection kits (DNA Genotek) customized for 23andMe (www.23andme.com). DNA extraction and genotyping were performed through 23andMe by the National Genetics Institute (NGI), a CLIA-certified clinical laboratory and subsidiary of Laboratory Corporation of America. One of two different Illumina arrays with custom content was used to provide genome-wide SNP data, the HumanOmniExpress (N=327) or HumanOmniExpress-24 (N=195; Do et al., 2011; Eriksson et al., 2010; Tung et al., 2011).

2.8. Quality control and polygenic scoring

PLINK v1.90 (Purcell et al., 2007) was used to apply quality control cutoffs and exclude SNPs or individuals based on the following criteria: missing genotype rate per individual >0.10, missing rate per SNP >0.10, minor allele frequency <0.01, and Hardy-Weinberg equilibrium p<1e-6.

Polygenic scores were calculated using PLINK's (Purcell et al., 2007) "--score" command based on published SNP-level summary statistics from a recent GWAS of serum vitamin D levels (25-hydroxyvitamin D; Jiang et al., 2018). SNPs from the vitamin D GWAS were matched with the same SNPs from the DNS. For each SNP the number of the alleles (0, 1, or 2) associated with vitamin D serum levels was multiplied by the effect estimated in the GWAS. The polygenic score for each individual was an average of weighted vitamin D-associated alleles. All SNPs matched with SNPs from the DNS were used regardless of effect size and significance in the original GWAS, as previously recommended (Dudbridge, 2013; Ware et al., 2017).

2.9. Statistical analysis

Descriptive statistics were obtained using SPSS version 25. Mplus version 7 (Muthén & Muthén, 2007) was used to conduct the linear regression analyses that examined the association between the vitamin D polygenic scores, the Big Five personality traits, and the p factor. Although our data is cross-sectional, we also conducted a mediation analysis (Hayes, 2017) in Mplus, to test the relationship between the vitamin D polygenic score, personality, and the p factor. Participants' sex (coded as 0=males, 1=females), age, ancestry (two genetic MDS components), SES, and BMI were included in the analyses as covariates. In all analyses, bias-corrected (BC) bootstrapping (set to 5,000) was used to allow for non-symmetric 95% confidence intervals (CIs). Specifically, indirect effects are likely to have a non-normal distribution, and consequently the use of non-symmetric CIs for the determination of significance is recommended (MacKinnon, Lockwood, & Williams, 2004). However, bias-corrected bootstrapping also has its faults (Hayes & Scharkow, 2013) and, consequently, as supportive evidence for the indirect effect, we also present the test of joint significance, which examines whether the *a path* (vitamin D polygenic scores to personality trait) and the *b path* (personality trait to the p factor, while controlling for the vitamin D polygenic scores) are significant. The MDS components, vitamin D polygenic scores, and personality scores were standardized (i.e., M=0, SD=1) in SPSS.

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3. Results and statistical analysis

Descriptive statistics are presented in Table 1. Correlations between the variables of interest are presented in Table 2. As shown in Table 2, the correlations between the Big Five personality traits and the p factor replicated the correlations from Caspi et al., (2014). The p factor showed a strong positive correlation with neuroticism (r=0.499), and moderate negative correlations with agreeableness and conscientiousness (r=−0.349 and r=−0.347, respectively). In our sample there was also a weak negative correlation with extraversion (r=−0.092).

3.1. Vitamin D polygenic scores, the Big Five Personality Traits, and the p factor

As shown in Table 3, after controlling for sex, age, ancestry (two genetic MDS components), SES, and BMI, of the Big Five personality traits, the vitamin D polygenic scores were significantly negatively associated with neuroticism (b=−0.15, SE=0.05, p=0.002, CI=[−0.24]-[−0.05]) and positively associated agreeableness (b=0.10, SE=0.04, p=0.019, CI=0.018–0.18), such that higher vitamin D polygenic scores were associated with lower levels of neuroticism and higher levels of agreeableness. The vitamin D polygenic scores were also significantly negatively associated with the p factor (b=−1.9, SE=0.60, p=0.002, CI=[−3]-[−0.71]). The associations with neuroticism and the p factor remained significant after applying the Bonferroni correction for multiple comparisons (p<0.05/6). Results remained the same when genotyping platform was included as a covariate.

As post-hoc supplementary analyses, we conducted separate linear regression analyses (controlling for sex, age, ancestry, SES, and BMI) with the vitamin D polygenic scores predicting the 6 facets of neuroticism. As shown in Table 4, the vitamin D polygenic scores explained the most variance in self-consciousness, and then in anxiety, hostility, and vulnerability.

3.2. Testing for statistical mediation

Theoretical models examining the association between personality and psychopathology have stressed the pervasive role of neuroticism as a robust predictor of future psychopathology (Jeronimus, Kotov, Riese, & Ormel, 2016; Lahey, 2009; Widiger & Oltmanns, 2017). Consequently, it is reasonable to assume that the direction of causation is from personality to mental health disorders. We therefore examined a mediation model, in which neuroticism was the mediator between the vitamin D polygenic scores and the p factor. As we already found the association between the vitamin D polygenic scores and neuroticism to be significant (*path a*), we next examined whether the association between neuroticism and the p factor was significant (*path b*). Indeed, higher neuroticism scores predicted higher levels of the p factor, while controlling for the vitamin D polygenic scores (b=7, SE=0.60, p<0.001, CI=6–8.4). The direct effect (the effect of the vitamin D polygenic scores on the p factor, while controlling for neuroticism), was not significant (b=−0.82, SE=0.54, p=0.12, CI=[−1.90]-[0.21]). Consistent with the significance of the *a* and *b paths*, the mediation was significant and negative (indirect effect=−1, SE=0.35, p=0.003, CI=[−1.76]-[−0.39]), suggesting that higher vitamin D polygenic scores are associated with lower neuroticism scores, which are associated with lower p factor scores. The proportion of

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the mediated effect was 56% (the indirect effect divided by the total effect). Results remained the same when genotyping platform was included as a covariate.

4. Discussion

In the current study, we found that higher GWAS-derived polygenic scores of vitamin D serum concentrations are associated with lower neuroticism and lower p factor scores. A mediation analysis further suggested that neuroticism may mediate the link between the vitamin D polygenic scores and the p factor. We chose neuroticism as the mediating variable, because it is a known risk factor for numerous mental disorders, such as anxiety, schizophrenia, and depression (Jeronimus et al., 2016; Lahey, 2009; Widiger & Oltmanns, 2017). Notably however, because our data is cross sectional, the mediation presented here is only suggestive, as we discuss below.

Neuroticism is a complex trait characterized by higher inhibition, shyness, irritability, and sadness (Costa & McCrae, 1995). The post-hoc regression analyses with the six facets of neuroticism suggested that the vitamin D polygenic scores were negatively related to all facets of neuroticism (anxiety, angry/hostility, depression, self-consciousness, impulsiveness, and vulnerability), although the associations with depression and impulsiveness were somewhat weaker.

Vitamin D may be a risk factor for both neuroticism and the p factor based on its actions in the brain. Vitamin D has been shown to play a role in several processes that affect brain function, including proliferation and differentiation of neural stem cells; calcium signaling; neurotransmission; neuroprotection; synaptic plasticity; and regulation of inflammation and oxygen reactive species (Groves, McGrath, & Burne, 2014). The widespread influence of vitamin D is further supported by the prevalence of vitamin D response elements, the DNA sequences vitamin D receptor binds to. Specifically, Ramagopalan and colleagues (2010) have found 2776 vitamin D receptor binding sites and 229 genes with significant changes in expression in response to vitamin D. These findings suggest causal pathways that could explain the links found in the current study between vitamin D and both neuroticism and the general psychopathology factor.

4.1 Limitations

Importantly, our study is limited in several ways. First, our sample was cross-sectional and consequently causality could not have been established and the direction of the associations between vitamin D, neuroticism, and the p factor remains to be determined in future studies. This is despite our use of a polygenic score for vitamin D levels which at first blush, may lead to a presumed inference of directionality from vitamin D polygenic scores to neuroticism and the p factor. However, such speculation at this point would be premature for a number of reasons, one of them being that summary statistics from GWASs include all the possible genetically affected influences on the phenotype of interest (Avinun, 2020; Gage, Smith, Ware, Flint, & Munafò, 2016). As high neuroticism may lead individuals to spend less time outdoors due to shyness, anxieties, and fears, it is possible that the genetic influences on neuroticism were also captured in the GWAS. In other words, if neuroticism leads to lower levels of vitamin D, this will lead to a co-occurrence of the two phenotypes,

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which would translate into also estimating the genetic influences on neuroticism in a GWAS of vitamin D. Similarly, if mental disorders lead to less sun exposure and/or a less balanced diet, in addition to capturing more direct biological influences on vitamin D synthesis, a GWAS of vitamin D may capture the genetic influences on the p factor.

A second limitation is that our sample of volunteer students at a top university may not be representative of the general population in terms of psychopathology. Third, our sample was restricted to non-Hispanic Caucasians, and results may differ in populations of different ancestries. Third, we did not have measures of the biologically active form of vitamin D (1,25-hydroxyvitamin D), which may differ from the levels of 25-hydroxyvitamin D. Future studies can examine the possible interaction between the levels of these two vitamin D metabolites in the context of neuroticism and the p factor. Last, we did not have measures of serum vitamin D levels to confirm the association with the polygenic score.

5. Conclusion

While our results are tentative and require further replication, they provide the first evidence, to our knowledge, for an association between lower vitamin D polygenic scores, higher neuroticism, and higher general psychopathology scores. Put differently, our findings support a genetic correlation between vitamin D levels, neuroticism, and the p factor. Further research is needed to shed light on whether vitamin D is a risk factor for neuroticism and/or the p factor and whether neuroticism mediates a link between vitamin D polygenic scores and the p factor. As both neuroticism (Jeronimus et al., 2016; Lahey, 2009; Widiger & Oltmanns, 2017) and the p factor may confer risk for numerous disorders, gaining a better understanding of their etiology could have a substantial contribution to public health, especially in light of the promise shown by vitamin D supplementation in depression (Spedding, 2014), all-cause mortality (Autier & Gandini, 2007), and circulating levels of the inflammatory marker C-reactive protein (Chen et al., 2014).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Vitamin D polygenic scores were derived from a GWAS of circulating vitamin D levels.
- Vitamin D polygenic scores negatively associated with neuroticism.
- Vitamin D polygenic scores negatively associated with the general psychopathology factor (p factor).
- Findings suggest shared genetic influences on vitamin D, neuroticism, and psychopathology.

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Table 1.

Descriptive statistics of study variables.

	Minimum	Maximum	Mean	SD
BMI^	16	39	22	3
Socioeconomic status	2	10	7.3	1.4
Neuroticism	25	160	83	22.2
Extraversion	54	169	121	21
Openness	57	176	126	19
Agreeableness	48	172	118	20
Conscientiousness	32	175	121	20
P factor scores	75	187	98	14

Note. BMI=Body mass index. BMI was calculated as (pounds/inches2)*703.

Prog Neuropsychopharmacol Biol Psychiatry. Author manuscript; available in PMC 2021 June 08.

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Table 2.

Correlations between the p factor, the Big Five, BMI, and SES.

	BMI	SES	Neuroticism	Conscientiousness	Agreeableness	Openness	Extraversion	P factor
BMI	1	−0.07	0.03	−0.07	−0.10*	0.03	0.04	0.08
SES		1	−.14**	0.05	−0.07	0.03	0.09*	−0.03
Neuroticism			1	−.37**	−0.21**	0.005	−0.28**	0.50**
Conscientiousness				1	0.05	−0.16**	0.11*	−0.35**
Agreeableness					1	0.24**	0.15**	−0.35**
Openness-to-experience						1	0.29**	0.02
Extraversion							1	−0.09*
P factor								1

Note.

* p<.05

** p<.01.

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Table 3.

Associations between the vitamin D polygenic scores and the Big Five.

Outcome	b	SE	Lower CI	Upper CI	R^2
Neuroticism	−0.15**	0.05	−0.24	−0.05	0.02
Extraversion	0.06	0.05	−0.04	0.15	0.002
Openness	−0.02	0.05	−0.11	0.07	0
Agreeableness	0.10*	0.04	0.02	0.18	0.008
Conscientiousness	0.06	0.05	−0.04	0.15	0.003

Note.

* p<.05

** p<.01.

CI= 95% bootstrapped confidence interval. R^2-variance explained by the vitamin D polygenic score. Controlling for sex, age, BMI, ancestry (2 genetic MDS components), and socioeconomic status.

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Table 4.

Associations between the vitamin D polygenic scores and the 6 facets of neuroticism.

Outcome	b	SE	Lower CI	Upper CI	R^2
Anxiety	−0.12*	0.05	−0.21	−0.03	0.01
Hostility	−0.13**	0.05	−0.22	−0.04	0.01
Depression	−0.10	0.05	−0.19	0.003	0.008
Self-Consciousness	−0.14**	0.05	−0.24	−0.05	0.02
Impulsiveness	−0.07	0.05	−0.16	0.03	0.004
Vulnerability	−0.11*	0.05	−0.21	−0.02	0.01

Note.

* p<.05

** p<.01.

R^2-variance explained by the vitamin D polygenic score. Controlling for sex, age, ancestry (2 genetic MDS components), SES, and BMI.