

## The Big Five personality traits and CNS arousal in the resting state

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### Abstract

Based on Eysenck's pioneering work, CNS arousal has long been considered an encouraging biological candidate that may explain individual differences in human personality. Yet, results from empirical studies remained inconclusive. Notably, the vast majority of published results have been derived from small samples, and EEG alpha power has usually served as exclusive indicator for CNS arousal. In this study, we selected  $N = 468$  individuals of the LIFE-Adult cohort and investigated the associations between the Big Five personality traits and CNS arousal by using the low-resolution electromagnetic tomography-based analysis tool VIGALL. Our analyses revealed that subjects who reported higher levels of extraversion and openness to experience, respectively, exhibited lower levels of CNS arousal in the resting state. Bayesian and frequentist analysis results were especially convincing for openness to experience. Among the lower-order personality traits, we obtained strongest evidence for neuroticism facet 'impulsivity' and reduced CNS arousal. We regard these findings as well in line with the postulations of Eysenck and Zuckerman and consistent with the assumptions of the 'arousal regulation model'. Our results also agree with meta-analytically derived effect sizes in the field of individual differences research, highlighting the need for large studies with at least several hundreds of subjects.

Keywords: Arousal, Big Five, EEG, Resting State, VIGALL, Extraversion, Neuroticism

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## 1 Introduction

2 Over the past decades, a substantial body of research has focused on the relationship between individual  
3 differences in human personality and the underlying biological mechanisms. Aside from a general interest  
4 to identify the biological factors that explain the great diversity in human behavior, research in this field  
5 has been motivated by theoretical concepts and empirical evidence linking personality traits to mental  
6 health outcomes (Maher & Maher, 1994; Strickhouser, Zell, & Krizan, 2017). Beyond this, personality  
7 traits have been proposed to constitute vulnerability factors for mental diseases, and affective disorders  
8 in particular (Akiskal, Hirschfeld, & Yerevanian, 1983; Barnett et al., 2011; Hensch et al., 2019;  
9 Jeronimus, Kotov, Riese, & Ormel, 2016; Klein, Kotov, & Bufferd, 2011). On this account, elucidating  
10 the biological basis of personality has not only been argued to provide valuable insights into the etiology  
11 of psychiatric diseases, but may also have important implications for identifying at-risk individuals,  
12 initiating early preventions, and tailoring treatments.

13 One of the most prominent trait approaches to describe and measure the structure of human  
14 personality is the Five-Factor Model (FFM; Goldberg, 1990; McCrae & Costa, 2008). The FFM is a  
15 taxonomy that strives for an economic description of the whole range of individual differences in  
16 personality by means of five overarching factors. These ‘Big Five’ personality traits encompass openness  
17 to experience, conscientiousness, extraversion, agreeableness, and neuroticism. With some limitations,  
18 the five-factor structure of personality has been shown to generalize across languages and cultures, and  
19 has been argued to be based on innate biological factors (Macdonald, 1998; McCrae et al., 2000; see also  
20 De Raad, 1998). In fact, evidence from twin studies and genome-wide complex trait analyses suggests  
21 that a substantial proportion of the Big Five variance is accounted for by genetics (Bouchard & McGue,  
22 2003; Lo et al., 2017; Vernon, Martin, Schermer, & Mackie, 2008). However, the biological mechanisms  
23 that bridge the effects of genetic variation on human personality still remain elusive. In order to provide  
24 an explanatory biological basis of human personality, various neuropsychological trait theories have been  
25 postulated, with Eysenck’s Arousal-Activation Theory of Extraversion and Neuroticism having attracted  
26 particular attention (Brocke & Battmann, 1992; Eysenck, 1967).

27 Eysenck’s Arousal-Activation Theory builds upon the early 1960s’ psychophysiological activation  
28 theories, according to which the ascending reticular activation system (ARAS) regulates central nervous  
29 system (CNS) arousal (Duffy, 1962; Malmö, 1959). Eysenck distinguishes two components of his  
30 conceptual nervous system: the reticulo-cortical brain system (i.e., ARAS) and the reticulo-limbic  
31 visceral brain system (VBS; Matthews & Gilliland, 1999). Excitation of the ARAS by incoming stimuli  
32 is referred to as ‘arousal’, whereas the excitation of the VBS by emotional stimuli is referred to as  
33 ‘activation’. An increase in activation has arousing effects, while arousal may also occur without  
34 activation (i.e., a unidirectional relationship). Eysenck postulated that extraverted individuals possess,  
35 on average, relatively low habitual levels of CNS arousal in the resting state, which he traces back to a

36 higher ARAS activation threshold (Brocke & Battmann, 1992). As a compensatory mechanism, they  
37 engage in arousal-enhancing behavior by seeking human interactions as well as novelty, change and  
38 excitement. In comparison, Eysenck describes neurotic individuals as emotionally hypersensitive, which  
39 he attributes to a lower activation threshold of the VBS (Brocke & Battmann, 1992). According to  
40 Eysenck, individuals with high levels of neuroticism are more susceptible towards stress and show a  
41 prolonged autonomic stress response.

42 The Arousal-Activation Theory has served as theoretical framework in numerous empirical studies  
43 (Küssner, 2017; Matthews & Gilliland, 1999). Eysenck himself referred to the alpha range of the human  
44 Electroencephalogram (EEG) as the standard measure of CNS arousal (Matthews & Gilliland, 1999). In  
45 line with Eysenck's postulations, a number of studies demonstrated higher resting-state EEG alpha  
46 power (indicating lower CNS arousal) in extraverted relative to introverted individuals (Gale, Coles, &  
47 Blaydon, 1969; Gale, Edwards, Morris, Moore, & Forrester, 2001; Hagemann et al., 2009; Smith et al.,  
48 1995). Several other studies failed to provide supportive evidence (Beauducel, Brocke, & Leue, 2006;  
49 Hagemann et al., 1999; Matthews & Amelang, 1993; Schmidtke & Heller, 2004). In addition, some  
50 investigators used EEG beta power as CNS arousal indicator and revealed both supporting and opposing  
51 evidence (Gale et al., 1969; Gram, Dunn, & Ellis, 2005; Matthews & Amelang, 1993). In sum, empirical  
52 investigations addressing the link between extraversion and CNS arousal have provided only inconsistent  
53 evidence for Eysenck's postulations.

54 A few studies also reported on the relationship between neuroticism and arousal. Based on  
55 Eysenck's postulations, researchers have argued that the habitual level of arousal may tend to be higher  
56 in labile (N-) extraverts and introverts when compared to their stable (N+) counterparts (Brocke, Netter,  
57 & Hennig, 2004). Consistent with this assumption, investigations in laboratory settings – including  
58 resting-state assessments – have previously been shown to elicit an arousal-enhancing 'first day in lab  
59 effect' (Huang et al., 2015) similar to the 'first night' effect in sleep medicine (Hirscher et al., 2015). This  
60 may especially affect individuals with high levels of neuroticism, who have been proposed to be more  
61 vulnerable towards stress. Notably, enhanced arousal levels in neurotic individuals would also tie in with  
62 the substantial genetic overlap demonstrated between neuroticism and major depression (Baselmans et  
63 al., 2019; Lo et al., 2017), with the latter having repeatedly been linked to enhanced and 'hyperstable'  
64 CNS arousal levels in the resting state (Hegerl, Wilk, Olbrich, Schoenknecht, & Sander, 2012; Sander,  
65 Schmidt, Mergl, Schmidt, & Hegerl, 2018; Schmidt et al., 2016, 2017; Ulke et al., 2017; Ulke, Tenke, et  
66 al., 2019; Ulke, Wittekind, et al., 2019). Despite these converging lines of research, available EEG studies  
67 have not yet provided supportive evidence for an association between CNS arousal and neuroticism (Gale  
68 et al., 2001; Hagemann et al., 2009, 1999; Savage, 1964). It should be noted, though, that the vast  
69 majority of published results on both neuroticism and extraversion have been derived from small samples  
70 with fewer than 100 subjects.

71 In comparison to previous approaches that predominantly used EEG alpha power as exclusive  
72 indicator for CNS arousal, above-mentioned studies that demonstrated a link between CNS arousal and  
73 depression made use of the Vigilance Algorithm Leipzig (VIGALL), an EEG- and EOG-based analysis  
74 tool that utilizes low-resolution electrotopography (Sander, Hensch, Wittekind, Böttger, & Hegerl,  
75 2016). VIGALL is typically applied to fifteen to twenty-minute resting-state recordings and incorporates  
76 information on the cortical distribution of the frequency bands alpha, delta, and theta. Beyond this,  
77 VIGALL features adaptive procedures that account for the individual differences in alpha peak frequency  
78 and EEG total power. Primarily, VIGALL was developed for investigating arousal disturbances in  
79 psychiatric samples and to objectively test the assumptions of the ‘arousal regulation model of affective  
80 disorders and attention-deficit hyperactivity disorder’ (Hegerl & Hensch, 2014). Similar to Eysenck’s  
81 theory, the arousal regulation model postulates that depressive- and manic-like behavior partly reflects  
82 an autoregulatory attempt to reduce and enhance habitual high and low arousal levels, respectively. A  
83 particular emphasis is put on the regulation of arousal, which is postulated to be unstable in clinical  
84 syndromes such as ADHD and mania and is expressed, at the behavioral level, in hyperactivity and  
85 sensation seeking (similar to the behavior frequently observed in overtired children). Major depression,  
86 in contrast, is postulated to be characterized by enhanced and hyperstable arousal, which is behaviorally  
87 expressed in avoidance of additional external stimulation. Noteworthy, by applying VIGALL, a number  
88 of empirical studies addressing arousal in depressive, bipolar, and ADHD patients have provided  
89 supportive evidence for the assumptions of the arousal regulation model (Hegerl et al., 2012; Strauß et  
90 al., 2018; Ulke et al., 2017; Ulke, Wittekind, et al., 2019; Wittekind et al., 2016). In addition, VIGALL  
91 has been validated in an fMRI and PET study (Guenther et al., 2011; Olbrich et al., 2009), against  
92 evoked potentials and parameters of the autonomous nervous system (Huang et al., 2017, 2018; Olbrich  
93 et al., 2011), against the Multiple Sleep Latency Test (Olbrich et al., 2015), and in a large study  
94 addressing the agreement with subjective ratings (Jawinski et al., 2017). These previous encouraging  
95 results raise the question, whether the application of VIGALL may leverage investigations on the role  
96 of arousal in human personality.

97 Against this background, we here sought to examine the relationship between the Big Five  
98 personality traits and CNS arousal in the resting state by making use of the EEG- and EOG-based  
99 analysis tool VIGALL. In accordance with previous theoretical and empirical indications, we  
100 hypothesized that CNS arousal is negatively associated with the personality trait extraversion and  
101 positively associated with neuroticism. Notably, each Big Five personality trait has been demonstrated  
102 to genetically overlap with psychiatric disorders (Lo et al., 2017), and each of the respective psychiatric  
103 disorders has been proposed to possess arousal-related pathophysologies (Hegerl & Hensch, 2014). On  
104 this account, we here examined the potential associations between CNS arousal and each Big Five  
105 personality trait. Given the relatively weak effect sizes in personality and individual differences research  
106 (Gignac & Szodorai, 2016; Schäfer & Schwarz, 2019), we considered a sample of several hundreds of

107 participants to derive our estimates. In this vein, we sought to contribute empirical evidence to the so-  
108 far unresolved issue of whether basic personality dimensions are reflected in habitual levels of arousal.

## 109 **Methods and Materials**

110 In the following sections, we report how we determined our sample size, all data exclusions (if any), all  
111 manipulations, and all measures in the study (Simmons, Nelson, & Simonsohn, 2012). All analysis scripts  
112 have been made publicly available on the repository of the Open Science Framework  
113 (<https://doi.org/10.17605/osf.io/ud38w>). The original data will be accessible via the Leipzig Health  
114 Atlas (<https://www.health-atlas.de>) upon publication of the peer-reviewed article.

### 115 **Sample**

116 Participants were drawn from the LIFE-Adult study, a population-based cohort study of 10,000  
117 inhabitants of the city of Leipzig, Germany (Loeffler et al., 2015). The scope of LIFE-Adult is to examine  
118 prevalences, genetic predispositions, and lifestyle factors of civilization diseases. All subjects underwent  
119 a comprehensive medical assessment program and completed various psychological surveys. We  
120 considered subjects with available resting-state EEG and NEO Personality Inventory data (562 subjects  
121 aged 40-79 years). Of these, we selected subjects who reported no current intake of EEG-affecting drugs  
122 and had no prior diagnosis of stroke, multiple sclerosis, Parkinson's disease, epilepsy, skull fracture,  
123 cerebral tumor, or meningitis (leaving 533 subjects). Based on a structured clinical interview for DSM-  
124 IV axis I disorders, we selected subjects without a history of psychotic disorders or substance dependence,  
125 and who were free of current anxiety and affective disorders (leaving 528 subjects). Moreover, EEGs with  
126 substantial artifacts ( $\geq 15\%$  of all EEG segments) and those showing low-voltage alpha, alpha variant  
127 rhythms, or pathological activity were not included. This resulted in  $N = 468$  eligible subjects (246  
128 females; mean age: 58.5 years). Participants gave written informed consent and received an expense  
129 allowance. All procedures were conducted according to the Declaration of Helsinki and were approved  
130 by the Ethics Committee of the University of Leipzig (263-2009-14122009).

### 131 **Questionnaire**

132 Subjects completed the German version of the revised NEO Personality Inventory (NEO-PI-R; Costa &  
133 McCrae, 1992; Ostendorf & Angleitner, 2004). The NEO-PI-R is a widely used self-report questionnaire  
134 that enables measuring the personality traits neuroticism, extraversion, openness to experience,  
135 agreeableness, and conscientiousness. The NEO-PI-R consists of 240 items and ratings are made on a  
136 five-point scale ranging from 'strongly disagree' to 'strongly agree'. Item scores are aggregated to the  
137 five NEO personality dimensions. The internal consistency (Cronbach's alpha) of the five overarching  
138 factors has been reported to range from 0.87 to 0.92 (Ostendorf & Angleitner, 2004). Test-retest  
139 reliability (1-month interval) has been reported to range from 0.88 to 0.91. Further, the NEO-PI-R allows  
140 to calculate scores for thirty personality facets, six facets per factor. The internal consistency and test-

141 retest reliability of the facets has been reported to range from 0.53 to 0.85 and 0.48 to 0.90, respectively  
142 (Ostendorf & Angleitner, 2004). NEO personality dimension and facet scores were transformed into sex-  
143 and age-normalized T-scores according to the NEO-PI-R manual.

#### 144 **Physiological data collection and processing**

145 Physiological data collection and processing was carried out as previously described (Jawinski et al.,  
146 2019, 2015). EEG assessments were conducted according to a standardized operating procedure.  
147 Assessments took place at three time slots: 8:30 am, 11:00 am, and 1:30 pm. During the twenty-minute  
148 resting condition, subjects lay on a lounge chair within a light-dimmed sound-attenuated booth. Subjects  
149 were instructed to close their eyes, relax and not to fight any potential drowsiness. In order to achieve  
150 similar initial levels of arousal activation, all subjects completed a brief arithmetic task immediately  
151 before the onset of recording. EEGs were derived from 31 electrode positions according to the extended  
152 international 10-20 system. Two bipolar electrodes served to record vertical and horizontal eye  
153 movements (EOGs). EEGs were recorded against common average reference with AFz ground. We used  
154 a QuickAmp amplifier (Brain Products GmbH, Gilching, Germany) and sampled recordings at 1000 Hz.  
155 EEG offline processing was carried out using Brain Vision Analyzer 2.0 (Brain Products GmbH, Gilching,  
156 Germany). EEGs were filtered (70 Hz low-pass and 0.5 Hz high-pass with 48 dB/Oct slope, 50 Hz notch)  
157 and rectified from eye movement, sweating, cardiac, and muscle artifacts using Independent Component  
158 Analysis (ICA). Graph elements (sleep spindles and K-complexes) were manually marked by experienced  
159 raters as previously described (Jawinski et al., 2017). Please see the publicly available VIGALL 2.1  
160 manual for further preprocessing details (Hegerl et al., 2016).

#### 161 **Assessment of brain arousal**

162 The assessment of brain arousal was carried out as described elsewhere (Jawinski et al., 2019, 2017).  
163 EEG-vigilance served as indicator for brain arousal and was measured using the Brain Vision Analyzer  
164 add-on VIGALL 2.1 (<https://www.deutsche-depressionshilfe.de/forschungszentrum/aktuellestudien/vig>  
165 [all-vigilance-algorithm-leipzig-2-1](https://www.deutsche-depressionshilfe.de/forschungszentrum/aktuellestudien/vig); Hegerl et al., 2016). Based on the cortical distribution and spectral  
166 composition of EEG activity, VIGALL assigns one of seven EEG-vigilance stages to each one-second  
167 EEG segment. EEG-vigilance stages correspond to active wakefulness (stage 0), relaxed wakefulness  
168 (stages A1, A2, A3), drowsiness (stages B1, B2/3), and sleep onset (stage C). Notably, stages A1-3 are  
169 characterized by predominant alpha activity, which may indicate relatively enhanced CNS arousal during  
170 eyes-closed resting-state conditions where stages of drowsiness (delta- and theta-activity) and sleep onset  
171 (occurrence of K-complexes and sleep spindles) are frequently observed. Therefore, the range of arousal  
172 stages implicated in the present study extends traditional approaches where higher EEG alpha power  
173 (relaxed wakefulness) has been used as exclusive indicator for reduced CNS arousal. We transformed  
174 assigned EEG-vigilance stages into values ranging from 7 (active wakefulness) to 1 (sleep onset) and  
175 calculated three outcome variables: mean vigilance, stability score, and slope index. Variable ‘mean

176 vigilance’ provides an estimate for the average level of EEG-vigilance during rest. The variables ‘stability  
177 score’ and ‘slope index’ particularly focus on the dynamics of EEG-vigilance. Lower scores indicate lower  
178 average levels and steeper declines, respectively, of EEG-vigilance. All three outcome variables have been  
179 validated, have been found test-retest reliable, and have previously been used as default parameters to  
180 summarize complex EEG-vigilance time-courses (Huang et al., 2017, 2015; Jawinski et al., 2017;  
181 Jawinski, Mauche, et al., 2016; Jawinski, Tegelkamp, et al., 2016).

## 182 **Statistical analyses**

183 The internal consistency of the NEO personality dimensions and facets was calculated using SPSS  
184 Statistics 25.0 (IBM corp.; Armonk, New York, USA). All frequentist analyses were carried out using  
185 Matlab R2018a (The MathWorks Inc., Natick, Massachusetts, USA). The nominal level of significance  
186 was set at  $p < .05$  (two-tailed). Further, p-values were adjusted by applying the False Discovery Rate  
187 (FDR) procedure according to Benjamini and Hochberg (1995). Associations with  $FDR < 0.05$  were  
188 regarded as significant after multiple testing correction. In addition, we sought to derive evidence for  
189 the alternate and null hypothesis, respectively, by calculating Bayes factors. Bayes factors reflect the  
190 likelihood ratio between the alternate and null hypothesis ( $BF_{10}$ ). Bayesian analyses were conducted  
191 with a moderate symmetrical 1/3 beta prior width using package ‘BayesFactor’ (Morey & Rouder, 2018)  
192 for R 4.0.1 (R Core Team, 2017).

193 First, we carried out Spearman correlations between the higher-order NEO personality dimensions  
194 (sex- and age-normalized T-scores) and the three EEG-vigilance variables (mean vigilance, stability  
195 score, and slope index). Next, we generated a permutation-based quantile-quantile plot (qq-plot) to  
196 examine whether the distribution of observed p-values differs from a random p-value distribution under  
197 the null hypothesis. On this account, for the set of 15 observed p-values (5 NEO personality dimensions  
198 x 3 EEG-vigilance variables), one million sets of 15 expected p-values were derived from correlations  
199 after data permutation. Original correlations within the domain of personality traits and the domain of  
200 EEG-vigilance variables were preserved, whereas original correlations between these domains were  
201 removed through random shuffling. Subsequently, in order to identify facets that particularly contribute  
202 to the observed associations, we conducted exploratory Spearman correlations between the thirty NEO  
203 personality facets (sex- and age-normalized T-scores) and the three EEG-vigilance variables. By analogy  
204 to the higher-order ‘Big Five’ analyses, we also generated a permutation-based qq-plot for the NEO  
205 personality facets. Analyses were repeated with sex, age, and daytime of EEG-assessment serving as  
206 covariates.

## 207 **Statistical power**

208 Power analyses were conducted using R package *pwr* (version 1.3-0; Champely, 2020), with effect sizes  
209 quantified as Spearman’s rho ( $r_S$ ). Given  $N = 468$  and  $\alpha = .05$ , power calculations revealed that  
210 associations with true effect sizes of  $r_S = 0.052$ ,  $r_S = 0.091$ , and  $r_S = 0.129$  were identified with a chance

211 of 20%, 50% and 80% ( $1-\beta$ ), respectively. After Bonferroni-correction ( $\alpha = .0033$ ; resembling the most  
 212 conservative case where the FDR procedure ends at the smallest observed p-value), power calculations  
 213 revealed that associations with true effect sizes of  $r_S = 0.097$ ,  $r_S = 0.135$ , and  $r_S = 0.173$  were identified  
 214 with a chance of 20%, 50% and 80% ( $1-\beta$ ), respectively. Supplementary Figure S1 shows the probabilities  
 215 of associations to reach the threshold of significance, given true effect sizes of up to  $r_S = 0.4$ .

## 216 Results

217 The descriptive statistics for the five higher-order NEO personality traits and the three EEG-vigilance  
 218 variables are shown in Table 1.

**Table 1** Descriptive statistics of NEO-PI-R scores and VIGALL 2.1 variables of EEG-vigilance

N = 468	Cronbach's $\alpha$	Mean	SD	Q1	Q2	Q3	Min	Max	Skew	Kurt
<b>NEO-PI-R</b>										
Neuroticism	0.906	44.95	8.77	39.00	45.00	52.00	20.00	71.00	-0.23	-0.29
Extraversion	0.899	51.69	9.83	45.00	52.00	58.00	21.00	79.00	-0.02	0.18
Openness	0.868	46.85	8.45	41.00	46.00	51.00	20.00	72.00	0.32	0.32
Conscientiousness	0.836	53.02	8.87	47.00	52.00	59.00	26.00	80.00	0.10	0.09
Agreeableness	0.881	54.73	9.04	48.00	54.00	61.00	30.00	80.00	0.30	0.03
<b>EEG-vigilance</b>										
Mean vigilance	-	5.09	1.06	4.43	5.40	5.89	1.93	6.76	-0.90	-0.03
Stability score	-	9.20	4.19	6.00	9.00	13.00	1.00	14.00	-0.58	-0.94
Slope index	-	-1.52	0.92	-2.26	-1.38	-0.74	-4.26	0.73	-0.57	-0.58

SD: standard deviation, Q1: quartile 1, Q2: quartile 2 (median), Q3: quartile 3, Min: minimum observed value; Max: maximum observed value; Skew: skewness, Kurt: excess kurtosis

219

220 The internal consistency (Cronbach's alpha) of the five NEO personality dimensions ranged between  
 221 0.84 and 0.91 and was thus comparable to previous reports (Ostendorf & Angleitner, 2004). The NEO  
 222 personality dimensions were significantly intercorrelated (suppl. Table S1), with the strongest correlation  
 223 observed between extraversion and openness to experience ( $r_S = .477$ ,  $p = 5E-28$ ). The internal  
 224 consistency of the NEO personality facets ranged between 0.46 and 0.83 (Cronbach's alpha and  
 225 intercorrelations shown in suppl. Figure S2). Intercorrelations between EEG-vigilance variables reached  
 226  $r_S \geq 0.82$  (suppl. Table S2). Regarding covariates, we observed that younger participants and those who  
 227 underwent the EEG assessment at later daytime exhibited a lower EEG-vigilance (e.g. mean vigilance;  
 228 age:  $r_S = .168$ ,  $p = 3E-4$ ; daytime:  $r_S = -.155$ ,  $p = 8E-4$ ). Although we used sex- and age-normalized T-  
 229 scores according to the NEO-PI-R manual, we observed some remaining associations between the NEO  
 230 personality traits and both sex and age. Detailed association results between covariates and our outcome  
 231 variables are shown in supplementary Table S3.



232 **Big Five personality traits and CNS arousal**

233 Spearman correlations between the five NEO personality dimensions (sex and age-normalized T-scores)

234 and the three EEG-vigilance variables are shown in Table 2.

**Table 2** Spearman correlations between NEO personality dimensions (T-Scores) and EEG-vigilance variables

<i>N</i> = 468	Mean vigilance				Stability score				Slope index			
	rho	<i>p</i>	FDR	BF <sub>10</sub>	rho	<i>p</i>	FDR	BF <sub>10</sub>	rho	<i>p</i>	FDR	BF <sub>10</sub>
Neuroticism	-.063	.170	.365	0.27	-.030	.515	.766	0.13	-.002	.972	.972	0.11
Extraversion	-.104	.025*	.082	1.29	-.096	.038*	.095	0.91	-.137	.003*	.023**	8.35
Openness	-.102	.027*	.082	1.20	-.121	.009*	.044**	3.23	-.173	2E-4*	.002**	121.33
Agreeableness	-.027	.561	.766	0.13	-.012	.791	.913	0.11	-.032	.496	.766	0.14
Conscientiousness	-.023	.624	.780	0.12	-.005	.913	.972	0.11	-.039	.399	.748	0.15

FDR: False Discovery Rate according to Benjamini and Hochberg; BF<sub>10</sub> Bayes factor showing the likelihood ratio between the alternate and null hypothesis (1/3 beta prior width).

\* *p* < .05 (two-sided nominal significance)

\*\* FDR < .05 (p-value corrected for all tested associations using FDR method)

235

236 Analyses revealed six associations with nominal significance (*p* < .05). Of these, three remained

237 significant after multiple testing correction (FDR < .05). We observed EEG-vigilance to be inversely

238 associated with the degree of extraversion (slope index:  $r_s = -.137$ , *p* = .003, FDR = .023, BF<sub>10</sub> = 8.35)

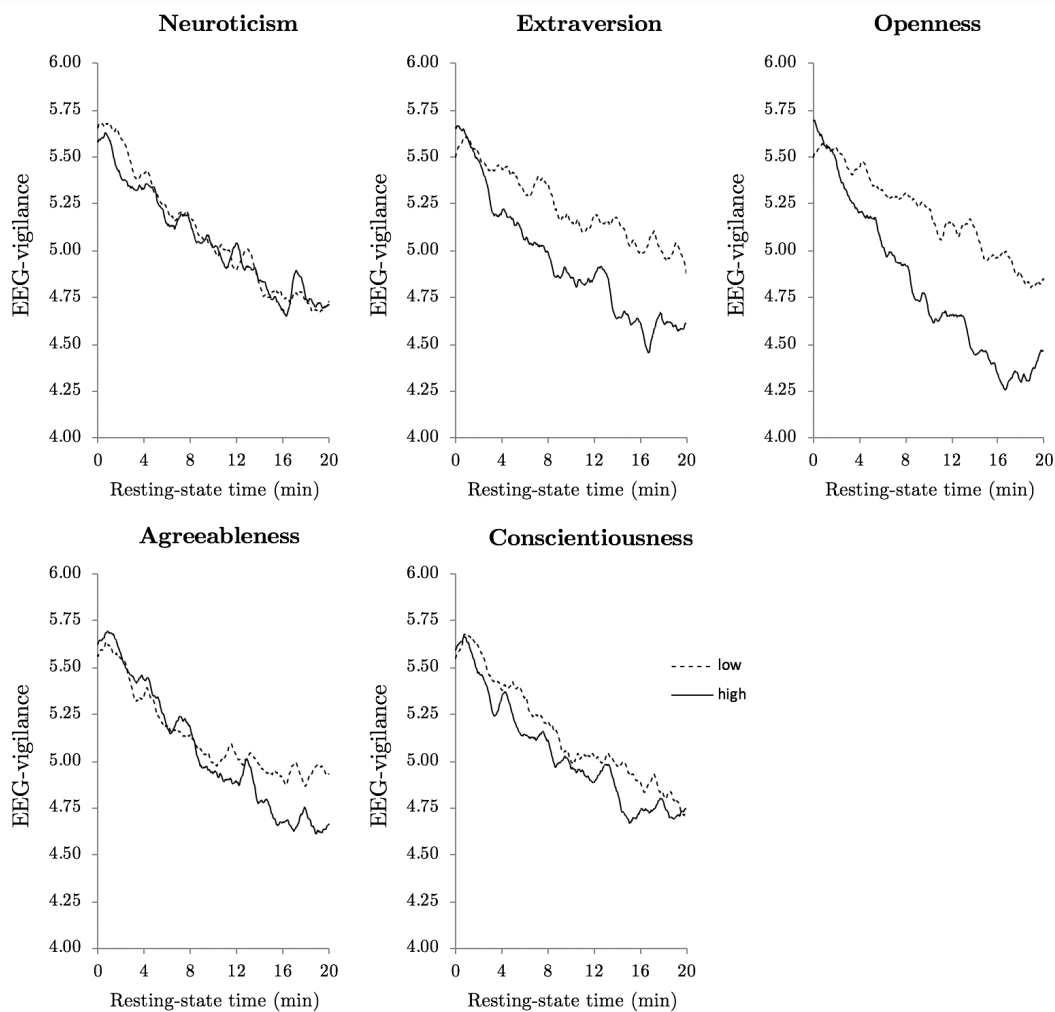
239 and openness to experience (stability score:  $r_s = -.121$ , *p* = .009, FDR = .044, BF<sub>10</sub> = 3.23; slope index:

240  $r_s = -.173$ , *p* = 2E-4, FDR = .002, BF<sub>10</sub> = 121.33). Subjects who reported higher levels of extraversion

241 and openness to experience, respectively, exhibited lower EEG-vigilance. For illustrative purposes, the

242 time-courses of EEG-vigilance stratified by groups scoring low vs. high on the respective Big Five

243 dimension (lower vs. upper quartile of the ascending distribution) are shown in Figure 1.

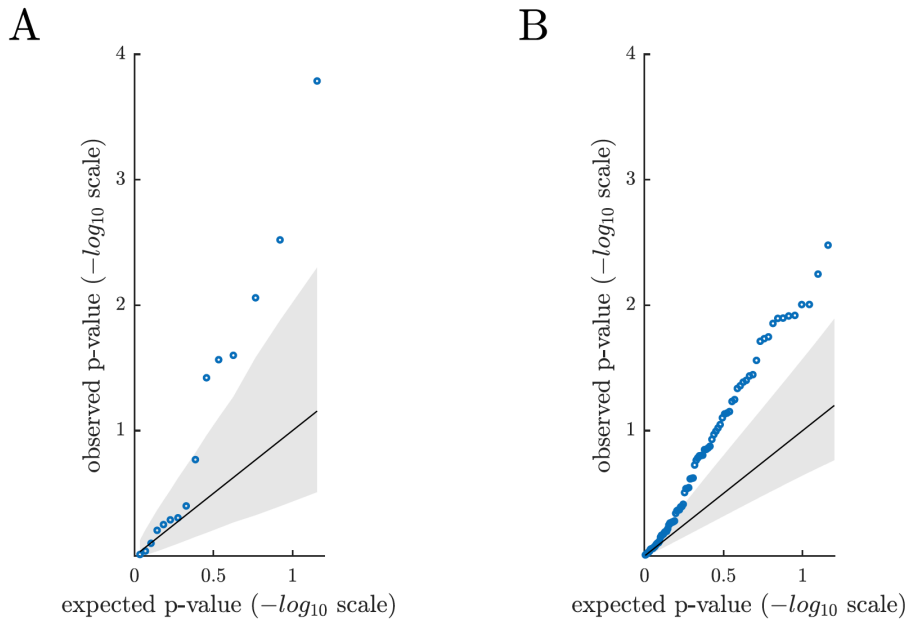


244

245 **Fig. 1** Time-courses of EEG-vigilance during the 20-minute eyes-closed resting-state condition stratified by groups  
246 scoring low vs. high on the respective Big Five scale (i.e. subjects with scores in the lower vs. upper quartile of the  
247 ascending distribution). Time-courses reflect simple moving averages (SMA), i.e., every data point represents an  
248 averaged 61-second interval of EEG-vigilance (data point in time  $\pm$  30 seconds). Statistical analyses revealed  
249 significant correlations between EEG-vigilance and both extraversion and openness to experience.  
250

251 We repeated our analysis by additionally adjusting correlations by sex, age, and daytime of EEG  
252 assessment (suppl. Table S4). This resulted in three associations reaching nominal significance. Of these,  
253 one remained significant after multiple testing correction (in this case the FDR corrected p-value is  
254 equivalent to the Bonferroni-corrected p-value): Subjects who reported higher levels of openness to  
255 experience exhibited lower EEG-vigilance (slope index:  $r_S = -.152$ ,  $p = .001$ ,  $FDR = .015$ ,  $BF_{10} = 23.40$ ).

256 In order to examine whether the distribution of observed p-values differs from a random p-value  
257 distribution, we generated a permutation-based qq-plot that takes into account the dependencies between  
258 association tests (Fig. 2A).



259

260 **Fig. 2** Permutation-based qq-plot showing the observed p-values from the association analyses (blue circles)  
261 plotted against the expected p-values under the null hypothesis. The solid diagonal line represents the mean expected  
262 p-values. The lower and upper bound of the grey area represent the 5<sup>th</sup> and 95<sup>th</sup> percentile (-log<sub>10</sub> scale) of the  
263 expected p-values. **A** Results based on the sex- and age-normalized T-scores of the NEO personality traits. **B** Results  
264 based on the sex- and age-normalized T-scores of the NEO personality facets. In total, qq-plots suggest that  
265 association analyses revealed stronger evidence than expected by chance.  
266

267 The qq-plot shows that the six strongest observed p-values exceed the 95<sup>th</sup> percentile (-log<sub>10</sub> scale) of  
268 the computed expected p-value distribution. In detail, only 0.7% of the one million sets of expected p-  
269 values contained at least six p-values below 0.038 (that is the 6<sup>th</sup> lowest observed p-value), and 0.2% of  
270 the one million sets of expected p-values contained at least one p-value below 2E-4 (that is the lowest  
271 observed p-value). Overall, the plot indicates that the distribution of observed p-values differs from a  
272 random p-value distribution under the null hypothesis. When additionally adjusting association results  
273 by sex, age, and daytime of EEG assessment, only the strongest observed association exceeded the 95<sup>th</sup>  
274 percentile of the expected p-value distribution (suppl. Figure S3A). In this regard, only 1.1% of the one  
275 million sets of expected p-values contained one p-value lower than 0.001 (that is the lowest observed p-  
276 value).

### 277 **NEO personality facets and CNS arousal**

278 To further elaborate the nature of the underlying associations, we carried out exploratory Spearman  
279 correlations between the 30 NEO facets (sex and age-normalized T-scores) and each of the 3 EEG-  
280 vigilance variables. Detailed association results are shown in supplementary Table S5. In total, 24 out  
281 of 90 correlations reached the level of nominal significance. The strongest association was observed for  
282 neuroticism facet 'impulsiveness' (mean vigilance:  $r_s = -.150$ ,  $p = .001$ ,  $BF_{10} = 19.88$ ). No other  
283 neuroticism facet reached nominal significance. Regarding extraversion, we found nominally significant

284 results for the facets ‘warmth’ (slope index:  $r_S = -.119$ ,  $p = .010$ ,  $BF_{10} = 2.90$ ), ‘assertiveness’ (slope  
285 index:  $r_S = -.109$ ,  $p = .018$ ,  $BF_{10} = 1.73$ ), ‘activity’ (slope index:  $r_S = -.114$ ,  $p = .014$ ,  $BF_{10} = 2.14$ ), and  
286 ‘positive emotions’ (slope index:  $r_S = -.116$ ,  $p = .012$ ,  $BF_{10} = 2.43$ ). Regarding openness to experience,  
287 we found significant associations for the facets ‘fantasy’ (slope index:  $r_S = -.094$ ,  $p = .041$ ,  $BF_{10} = 0.85$ ),  
288 ‘aesthetics’ (slope index:  $r_S = -.137$ ,  $p = .003$ ,  $BF_{10} = 8.60$ ), ‘feelings’ (slope index:  $r_S = -.137$ ,  $p = .003$ ,  
289  $BF_{10} = 8.27$ ), ‘actions’ (slope index:  $r_S = -.109$ ,  $p = .018$ ,  $BF_{10} = 1.68$ ), and ‘ideas’ (slope index:  $r_S = -$   
290  $.128$ ,  $p = .006$ ,  $BF_{10} = 4.76$ ). We also observed nominally significant results for agreeableness facet  
291 ‘tender-mindedness’ (slope index:  $r_S = -.145$ ,  $p = .002$ ,  $BF_{10} = 14.40$ ) and conscientiousness facet  
292 ‘achievement striving’ (slope index:  $r_S = -.135$ ,  $p = .003$ ,  $BF_{10} = 7.65$ ).

293 By analogy to the NEO personality dimension analyses, we generated a permutation-based qq-  
294 plot to examine whether the distribution of observed p-values of the NEO personality facets differs from  
295 a random p-value distribution (Fig. 2B). Again, the qq-plot indicates that association analyses revealed  
296 stronger evidence than expected by chance. Notably, consistent with the Big Five results, we observed  
297 an attenuation of effect sizes when additionally adjusting sex- and age-normalized T-Score correlations  
298 by sex, age and daytime of EEG-assessment (suppl. Table S6). The distribution of observed vs. expected  
299 p-values after adjusting T-Scores is shown in supplementary Figure S3B, with a large proportion still  
300 exceeding the 95<sup>th</sup> percentile of expected p-values.

## 301 Discussion

302 In this study, we investigated the association between the Big Five personality traits and CNS arousal  
303 in the resting-state by making use of the EEG- and EOG-based analysis tool VIGALL. Our primary  
304 analysis suggests that, after multiple testing correction, CNS arousal is negatively associated with the  
305 degree of extraversion and openness to experience: Subjects who reported higher levels of extraversion  
306 and openness to experience, respectively, showed steeper declines of EEG-vigilance. In addition, when  
307 considering all tested associations between the Big Five personality traits and CNS arousal, we observed  
308 overall stronger effects than expected by chance. This finding was supported by association results of  
309 the thirty NEO personality facets. Facet analyses also revealed that the observed associations of the  
310 higher-order Big Five traits and CNS arousal were not driven by a single facet with a distinct, strong  
311 effect but rather appeared to arise from a distributed pattern of associations across several facets.  
312 Notably, for the majority of nominally significant associations ( $p < 0.05$ ), Bayesian analysis revealed  
313 only anecdotal evidence for the alternate hypothesis ( $BF_{10}$  ranging between 1 and 3). In addition, when  
314 taking into account potential confounders, we observed a general attenuation of effect sizes, with several  
315 associations dropping below the nominal and FDR-corrected level of significance. Further, we did not  
316 obtain evidence for an association of CNS arousal and neuroticism, a personality trait that we regard as  
317 highly plausible candidate for arousal alterations. Overall, across frequentist and Bayesian analyses and

318 irrespective of accounting for potential confounders or not, we obtained the strongest and most  
319 compelling evidence for a link between openness to experience and CNS arousal.

320 To our knowledge, this investigation is the largest EEG study so far addressing the link between  
321 CNS arousal and the Big Five personality traits. In keeping with this, the statistical power to detect  
322 associations in this study was substantially higher when compared to the vast majority of previous  
323 investigations, which usually featured a sample size fewer than 100 subjects. Given the present study  
324 design and analysis procedure, the achieved statistical power enables to conclude that neuroticism is  
325 unlikely to account for more than 4% ( $r_s \geq 0.2$ ) of the variance in CNS arousal, since the probability ( $1 -$   
326  $\beta$ ) of identifying such an effect at  $p < 0.05$  exceeded 99.98% (see suppl. Fig. S1 for a power plot).  
327 Similarly, extraversion surpassed the FDR-corrected but not the Bonferroni-adjusted level of significance,  
328 with the latter being reached with a probability above 92% given a true effect size of  $r \geq 0.20$ . Thus, if  
329 extraversion and neuroticism are truly associated with CNS arousal, correlations are certainly below  $r$   
330  $= 0.20$ . This is well in agreement with a study of 708 meta-analytically derived correlations in the field  
331 of personality and individual differences research, suggesting a median reported effect size of  $r = 0.19$   
332 (Gignac & Szodorai, 2016). Notably, when considering preregistered studies only, the median effect size  
333 has been reported to be even lower ( $r = 0.12$ ; Schäfer & Schwarz, 2019). Accordingly, to elucidate the  
334 biological basis of individual differences in human personality, we believe that there is an urgent need  
335 for large (collaborative) studies with at least several hundreds and preferably thousands of subjects.

336 The present study adds empirical results to the ongoing debate of whether extraverted individuals  
337 exhibit lower habitual levels of CNS arousal. Consistent with the theoretical assumptions, our primary  
338 analyses provided supportive evidence for a negative correlation between extraversion and arousal.  
339 Nevertheless, there remain some reservations that we would like to outline. First, although we used sex-  
340 and age-normalized T-scores, we still observed associations between the NEO personality scores and  
341 both sex and age (suppl. Table S3). After considering sex and age as additional covariates, the observed  
342 associations between extraversion and CNS arousal did not remain significant after multiple testing  
343 correction. Hence, the present results do not provide stringent support for extraversion to share unique  
344 variance with CNS arousal beyond the effects of sex and age. Second, Bayesian analyses provided only  
345 anecdotal to moderate evidence for the proposed link. This may partly be explained by the selected  
346 priors. Here, we used a symmetrically scaled 1/3 beta prior, which is the default setting of R package  
347 ‘BayesFactor’ (Morey & Rouder, 2018). This prior corresponds to the expectation that with an 80%  
348 probability the true effect falls in between  $r = -0.5$  and  $r = 0.5$ . However, in light of the reported effect  
349 sizes in the field of individual differences research (Gignac & Szodorai, 2016; Schäfer & Schwarz, 2019),  
350 this prior width might still be considered too wide, and resulting Bayes factors may thus show some bias  
351 towards favoring the null hypothesis. Notably, the software package JASP, which is widely used in the  
352 social and behavioral sciences, implicates an even more naive uniform prior as default setting (JASP

353 Team, 2020). Hence, given the rising popularity of Bayesian analyses in the life sciences, we feel that  
354 the selection of adequate prior widths may be one crucial topic of the future scientific debate. Taken  
355 together, we here find some evidence supporting Eysenck's postulations concerning the link between  
356 extraversion and CNS arousal, but the observed effect strength suggests that even larger sample sizes  
357 are required to establish reliable associations that withstand a rigorous control for potential confounders.  
358 An elaborated a priori knowledge of the expected effect sizes may further increase the study power.

359 Although we did not obtain evidence for a link between CNS arousal and neuroticism, exploratory  
360 analyses revealed indications for a negative association with neuroticism facet 'impulsiveness'. This result  
361 was the most compelling among all facet associations and remained significant after multiple-testing  
362 correction. Interestingly, impulsiveness showed relatively low correlations with the other neuroticism  
363 facets and, in contrast to them, correlated positively with facets of extraversion and openness to  
364 experience (suppl. Fig. S2). In this light, impulsiveness may be considered as rather atypical facet of the  
365 higher-order trait neuroticism. Notably, the observation of low habitual arousal levels in individuals  
366 exhibiting impulsive behavior is well in line with previously proposed concepts (Eysenck, 1967; Hegerl  
367 & Hensch, 2014; Zuckerman, 1979).

368 In comparison to neuroticism facet 'impulsiveness', our analyses did not reveal indications for a  
369 link between neuroticism facet 'depression' and CNS arousal. By applying the Vigilance Algorithm  
370 Leipzig, several previous studies provided supportive evidence for an association between clinical  
371 depression and enhanced CNS arousal in the resting state (Hegerl et al., 2012; Sander et al., 2018;  
372 Schmidt et al., 2016, 2017; Ulke et al., 2017; Ulke, Tenke, et al., 2019; Ulke, Wittekind, et al., 2019;  
373 Wittekind et al., 2016). Although the present study included subjects without a current depression  
374 diagnosis, it can be assumed that alterations in CNS arousal occur in both the normal and pathological  
375 range of human behavior. This is consistent with the view that personality traits and psychopathology  
376 are no distinct entities, but may rather manifest along a common spectrum of functioning (Widiger,  
377 2011). This argumentation also ties in with the postulations of the Research Domain Criteria Project  
378 (RDoC), according to which mental diseases can be considered to fall along multiple continuous trait  
379 dimensions, with traits ranging from normal to the extreme (Cuthbert & Insel, 2013). Intriguingly, the  
380 RDoC project considers 'arousal and regulatory systems' as one out of five fundamental domains to  
381 describe and classify psychiatric disorders. In the present study, the lack of evidence for an association  
382 between CNS arousal and 'depression' may be explained by lower effect sizes among healthy subjects  
383 relative to the study of healthy control vs. in-patient samples.

384 Across all analyses, we obtained the strongest evidence for an association between the Big Five  
385 personality trait openness to experience and CNS arousal. Bayes factors indicated 'extreme evidence'  
386 ( $BF_{10} > 100$ ) and 'strong evidence' ( $BF_{10}$  ranging from 10 to 30) for this link, respectively, depending  
387 on whether we considered zero-order correlations or whether sex, age, and daytime of EEG assessment

388 served as covariates. Interestingly, previous genetic correlation analyses suggest a positive association  
389 between openness to experience and major depression as well as bipolar disorder (Lo et al., 2017). These  
390 mental diseases have both been argued to possess arousal-related pathophysiologies (Hegerl & Hensch,  
391 2014). However, since manic and depressive-like behavior have been postulated to be linked to habitually  
392 low vs. high arousal levels, it remains difficult to deduce the sign of the potential association between  
393 openness to experience and CNS arousal. Importantly, previous investigations have shown that openness  
394 to experience positively correlates with sensation seeking (Aluja, García, & García, 2003). Further,  
395 openness to experience has been reported to positively correlate with extraversion, which is also shown  
396 in the present dataset (suppl. Table S1). On this account, we regard the present findings of lower arousal  
397 levels in subjects scoring high on openness to experience as consistent with the concepts of Eysenck  
398 (1967) and Zuckerman (1979).

399 Our study poses some limitations that need to be addressed. First, our participants were, on  
400 average, 58 years old, and reported association strengths may not generalize across other age groups. In  
401 particular, we previously observed a general tendency towards stronger effect sizes for arousal  
402 associations among the younger age groups (Jawinski et al., 2017). This might be explained by the higher  
403 EEG total power in younger adults and a possibly related higher accuracy of EEG-vigilance  
404 classifications. Further, we here addressed the relationship between individual differences in personality  
405 and habitual levels of CNS arousal by means of an EEG resting-state paradigm. However, one major  
406 emphasis of Eysenck's theory is put on the differential performance of extraverts and introverts as a  
407 function of arousal-enhancing situational factors (Brocke & Battmann, 1992). Thus, an interesting future  
408 direction might be the use of VIGALL in experimental studies with behavioral performance outcomes  
409 (e.g., as done previously by Huang et al., 2017) while taking into account the 'hedonic tone of an  
410 individual', i.e., the preferred level of excitation. Lastly, it should be noted that the present study sought  
411 to answer the question of whether CNS arousal but not the EEG, in general, is predictive for basic  
412 personality traits. Stronger associations may be derived by the application of machine learning models  
413 trained on the EEG to directly predict human personality (for an example see Li et al., 2019).

## 414 **Conclusion**

415 To the best of our knowledge, this study is the largest EEG study so far addressing the relationship  
416 between the Big Five personality traits and habitual levels of CNS arousal. Concerning Eysenck's Arousal  
417 Activation Theory, our results provide some support for extraversion and no support for neuroticism to  
418 be linked to CNS arousal. Intriguingly, Bayesian and frequentist analyses revealed convincing evidence  
419 for a link between openness to experience and lower levels of CNS arousal. In addition, among the lower-  
420 order personality traits, we obtained evidence for neuroticism facet 'impulsivity' and reduced CNS  
421 arousal. We regard these findings as well in line with the postulations of Eysenck and Zuckerman and  
422 consistent with the assumptions of the arousal regulation model. In total, the present study results agree

423 with meta-analytically derived effect sizes in the field of personality and individual differences research,  
424 highlighting the need for large (collaborative) studies with at least several hundreds of subjects.

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## 432 Conflict of Interest

433 The authors have no financial or competing interests to declare.

## 434 Supplementary Material

435 Supplementary information is available at bioRxiv online.

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