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# Personality traits relate to chronotype at both the phenotypic and genetic level

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**Abstract**

**Introduction:** Diurnal preferences have been linked to personality but often with mixed results. The present study examines the relationships between sleep timing (chronotype), diurnal preferences, and the Five-Factor Model of personality traits at the phenotypic and genetic level.

**Methods:** Self- and informant-reports of the NEO Personality Inventory-3, self-reports of the Munich Chronotype Questionnaire, and DNA samples were available for 2,515 Estonian adults ($M_{age}$ = 45.76 years; 59% females). Genetic correlations were obtained through summary statistics of genome-wide association studies.

**Results:** Results showed that higher Conscientiousness and lower Openness to Experience were significant predictors of earlier chronotype. At the level of facets, we found that more straightforward (A2) and excitement-seeking (E5), yet less self-disciplined (C5) people were more likely to have later chronotypes. The nuance-level Polypersonality score was correlated with chronotype at $r = .28$ ($p < .001$). Conscientiousness and Openness were genetically related with diurnal preferences. The polygenic score for morningness–eveningness significantly predicted the Polypersonality score.

**Conclusion:** Phenotypic measures of chronotype and personality showed significant associations at all three of levels of the personality hierarchy. Our findings indicate that the relationship between personality and morningness–eveningness is partly due to genetic factors. Future studies are necessary to further refine the relationship.

**KEYWORDS**

chronotype, domains, facets, FFM personality traits, items, morningness–eveningness, polygenic scores, self- and informant-reports | genetic correlations

## 1 | INTRODUCTION

Getting up at six in the morning without the use of an alarm clock, instantly going for a jog, showering quickly and then going straight to productive work is how one would imagine a typical morning person. This, of course, is an exaggerated example, but there is a grain of truth behind this generalization—there are substantial differences among individuals in their sleep timings (chronotype) and preferences (morningness–eveningness), which are related to many important behavioral outcomes (Keller et al., 2016; Lucassen et al., 2013; Rahafar et al., 2018; Randler et al., 2014; Susman et al., 2007; Urbán et al., 2011). Morningness–eveningness has been linked to personality in past research (e.g., Lipnevich et al., 2017; Randler et al., 2017; Tsaousis, 2010), with the proposition that some of the genetic polymorphisms that influence circadian rhythms and thereby people's sleep preferences, also affect personality (Jiménez et al., 2017). Differently from previous research, the present study examines not only actual sleep timing (chronotype), but also genetic morningness–eveningness due data availability. The aim of the study is to establish the personality–chronotype relationship and to better understand its underlying mechanisms while examining how the Five-Factor Model (FFM) of personality domains, facets, and items ("nuances") are associated with chronotype/morningness–eveningness at both the phenotypic and genetic level.

## 1.1 | Chronotype and morningness–eveningness

Individual differences in people's sleep times are often referred to as chronotype (Roenneberg, 2012) whereas diurnal preferences are called morningness–eveningness (Horne & Östberg, 1976). Chronotype is largely influenced by not only circadian rhythms and the light–dark cycle but also societal and work schedules as well as self-selected human behavior (Czeisler & Buxton, 2017; Roenneberg et al., 2019). In our study, we assessed chronotype with the Munich Chronotype Questionnaire (MCTQ) that describes chronotype as a biological phase of entrainment to light and darkness of the 24-hr day rather than preference (Roenneberg, 2015). The questionnaire assesses one's sleep patterns on a typical work and free day and allows calculating the time of mid-sleep on free days (MSF). MSF is the mid-point between sleep onset and wake-up time and is often used as a measure of chronotype. Chronotype as conceptualized with the MCTQ is a continuous variable and has been shown to be normally distributed (Roenneberg et al., 2003). An early chronotype tends to go to bed and wake up early, whereas a late chronotype tends to go to bed late and wakes up late. The MCTQ has shown convergent validity with the Morningness–Eveningness Questionnaire (MEQ; Horne & Östberg, 1976)—an assessment of people's sleeping preferences—with MSF scores correlating significantly with the morningness–eveningness score ($r = -.73$, Zavada et al., 2005).[1] Genetic studies have been solely based on morningness–eveningness (e.g., Jones et al., 2016) which is why our genetic results will be based on morningness–eveningness.

The MCTQ and MEQ closely measure the neuroendocrine underpinnings of chronotype and morningness–eveningness, with MSF corrected for sleep debt being the strongest predictor of dim light melatonin onset, followed by MEQ (Kantermann et al., 2015). Dim light melatonin onset is a "gold standard" for a circadian phase marker (Kantermann & Eastman, 2018).

## 1.2 | Associations of morningness–eveningness with the FFM personality traits

Previous studies have explored the relationship between personality and diurnal preferences (i.e., morningness–eveningness), but not chronotype. These studies have found somewhat mixed and even contradictory results which, partly, may be due to different conceptualizations of personality (Lipnevich et al., 2017). Moreover, even though most studies have operationalized morningness–eveningness as a one-dimensional construct, there are also some more recent studies that have measured morningness and eveningness on two separate dimensions (Lipnevich et al., 2017), making the comparison of empirical results published in different studies difficult.

When summarizing the existing evidence on the personality–diurnal preferences relationship, a meta-analysis by Lipnevich and colleagues (2017) showed weak-to-moderate associations between morningness–eveningness and the FFM personality traits. The study reported that the strongest association was between morningness and Conscientiousness ($r = .27$; greater morningness related to higher Conscientiousness), with personality traits altogether explaining about 11% to 16% of the variance in diurnal preferences. Other studies and meta-analyses have reported roughly similar findings (Carciofo et al., 2016; Duggan et al., 2014; Randler, 2008; Randler et al., 2017; Tsaousis, 2010). Lipnevich and colleagues (2017) further reported that associations were weaker between morningness–eveningness and other FFM traits, with meta-analytic correlations with morningness–eveningness as a continuous dimension ranging from $r = -.07$, .02, .00, to .12, for Neuroticism, Extraversion, Openness to Experience (Openness), and Agreeableness, respectively, with higher scores indicating greater morningness.

Many studies have looked into the associations between morningness–eveningness and single personality traits separately and have not used multiple regression models that incorporate all personality traits and relevant sociodemographic variables. Of the few exceptions is a study by Randler and colleagues (2017) which found that all five FFM domains were significantly related to morningness–eveningness. Yet, when using the FFM personality traits with age and gender to predict morningness–eveningness in a multiple regression model, Randler et al. (2017) found that only three personality traits—Openness, Conscientiousness, and Extraversion—remained significant predictors of morningness–eveningness.

Thus, based on this and other studies that have demonstrated the importance of gender, age, and education level in chronotype/morningness–eveningness (e.g., Barclay et al., 2010; Paine et al., 2006; Randler et al., 2017; Roenneberg & Merrow, 2007; Walker et al., 2014), and personality traits (e.g., McCrae et al., 2004; Schmitt et al., 2008), we will adjust our analyses for these demographic variables. Given that time of year has a significant effect on the epidemiological variation in sleep duration (Allebrandt et al., 2014; Randler & Rahafar, 2017), we will also control for the effect of seasonal variation on chronotype.

The above-mentioned studies have examined the associations between the FFM personality domains and diurnal preferences. Narrower facets however lie beneath the broad FFM factors in the personality hierarchy that are also known to contribute to the understanding and prediction of behavior (Mõttus, 2016; Paunonen & Ashton, 2001; Paunonen et al., 2003). For example, it has been reported that there is a direct pathway between Self-discipline (C5), a facet of Conscientiousness and health behavior (Hagger-Johnson & Whiteman, 2007). The lowest level of the personality trait hierarchy is conceptualized as single-personality questionnaire items or "nuances" (McCrae, 2015). Several studies have shown that the associations between a trait (e.g., Neuroticism and/or N5: Impulsiveness) and an outcome variable (e.g., Body Mass Index) are mostly due to two specific items (Terracciano et al., 2009; Vainik et al., 2015). For this reason, the first aim of our study is to examine the relationships between chronotype and the FFM personality traits not only at the domain but also at the facet and item levels in order to provide a more nuanced understanding of the associations between the two constructs.

## 1.3 | Genetic mechanisms of the personality–morningness–eveningness association

Even though the relationships between personality traits, such as Conscientiousness, and diurnal preferences are well established, less is known about the mechanisms underlying these relationships. In a recent longitudinal study that tried to establish the causality between diurnal preferences and personality, Stolarski et al. (2021) suggested that Conscientiousness and morningness might share underlying genetic mechanisms. Both morningness–eveningness and the FFM personality traits are rooted in biology and are substantially heritable—according to twin studies, about 50% of the variance in morningness–eveningness (e.g., Barclay et al., 2010; Hur, 2007; Koskenvuo et al., 2007), and 40%–60% of the variance in the FFM personality traits (Jarnecke & South, 2015; Vukasović & Bratko, 2015) can be attributed to genetics.

More recently, the results of behavioral genetics studies have been supported by DNA-based methods such as genome-wide association studies (GWAS) that test associations between millions of known DNA variants, called single-nucleotide polymorphisms (SNPs), and phenotypic traits in samples consisting of thousands of humans (Smith-Woolley et al., 2019). GWAS, for instance, have identified 351 loci for morningness–eveningness (Jones et al., 2019) and 136 loci for Neuroticism (Nagel et al., 2018). A recent study has shown that one locus for worry/vulnerability which is a factor of Neuroticism has also been linked with morningness–eveningness (Hill et al., 2019).

GWAS data allow the calculation of genetic correlations between pairs of traits, even between traits that have never been measured in the same sample (Harden & Koellinger, 2020). Genetic correlations can be used to identify shared genetic bases (Bulik-Sullivan et al., 2015), but they do not themselves inform about causal mechanisms or imply a direct effect of two traits (Harden & Koellinger, 2020).

The effect sizes of SNPs in predicting complex traits like morningness–eveningess and personality are usually very small, with each SNP explaining less than 0.1% of the variance (Gratten et al., 2014). Thus, since it is assumed that genetic effects are additive, more variance can be explained when considering the effects of SNPs jointly. By computing the sum of SNPs corresponding to a phenotype of interest, weighted by the effect size estimates across thousands of SNPs, it is possible to establish a genetic score for each individual in an independent sample (Choi et al., 2020; Smith-Woolley et al., 2019). These genetic scores, often called genome-wide polygenic scores (PGSs), allow DNA-based predictions for a wide range of phenotypic traits (Smith-Woolley et al., 2019).

With this in mind, the second aim of the present study is to examine if and to what extent the phenotypic correlations between chronotype and the FFM personality traits can be explained by genetic factors. We first examined the genetic correlations between morningness–eveningness and personality to describe the genetic relationship between the two traits using summary statistics of GWAS. To further explore how genotypic morningness–eveningness was related to all three levels of the personality hierarchy, we use the PGS for morningness–eveningness to not only link genetic morningness–eveningness with personality domains, but also facets and nuances.

## 1.4 | Aims of the present study

In sum, the first aim of our study is to examine the phenotypic relationships between the FFM personality traits and chronotype as conceptualized and assessed with the MCTQ (Roenneberg et al., 2003, 2007) in a large population-based sample of Estonian adults. The present study advances the field by examining the relationships between chronotype and the FFM personality traits not only at the domain but also at the facet and item levels. To better understand the potential genetic mechanisms of the relationship, we secondly investigate whether morningness–eveningness and personality are correlated with each other genetically. We also investigate whether PGS for morningness–eveningness is associated with the phenotypic variability throughout the hierarchy of FFM personality traits.

## 2 | METHOD

### 2.1 | Participants

The participants for this study came from the Estonian Biobank cohort (currently over 200,000 individuals), which is a large-scale sample of the Estonian adult population (Leitsalu et al., 2014). Of those, 3,608 participants had personality and genotype data available. We used these participants' data only for the calculation of the 20 principal components in the polygenic score analysis (see Polygenic Scores below for more detail). A subset of 2,346 participants had complete chronotype data and did not work in shifts. Further, 169 participants had personality and chronotype data available and did not work in shifts but were not genotyped. Therefore, the sample who had phenotypic personality and chronotype data available consisted of 2,515 participants, which we will use in our analyses unless mentioned otherwise. Their mean age was 45.22 years (*SD* = 16.70). Of those 1,492 (59.32%) were female. Both self-and informant-ratings of personality were available for majority of the sample (93.68%). For around half of the participants (*n* = 1,279; 50.85%), the highest level of educational attainment was secondary or secondary vocational education, followed by 42.98% with a university degree (*n* = 1,081), and 6.16% (*n* = 155) with basic education (i.e., nine years of compulsory comprehensive school).

Each participant was asked to nominate someone who knew them well (66.20% females, 26.96% male, 6.84% unknown; mean age = 41.41 years, *SD* = 15.75) to fill out the personality questionnaire and answer questions about their relationship to the participant. The highest level of educational attainment for about half of the informants (*n* = 1,171; 46.56%) was secondary or secondary vocational education, followed by 41.47% (*n* = 1,043) with higher education and 4.45% (*n* = 112) with basic education. Level of educational attainment was not known for 7.51% (*n* = 189). On average, informants had known the participant for 22.83 years (*SD* = 14.74), ranging from only a few months to 74 years. Most of the participants (*n* = 1,138; 45.25%) nominated their spouse or partner, followed by a parent (*n* = 392; 15.59%), a friend (*n* = 366; 14.55%), their child or grandchild (*n* = 187; 7.44%), an acquaintance (*n* = 60; 2.39%), another relative (*n* = 58; 2.31%), or a grandparent (*n* = 11; 0.44%). The type of relationship was not specified for 6.40% (*n* = 161).

The dataset, or parts of it, has been used in other studies (e.g., Kööts-Ausmees et al., 2016; Lenneis et al., 2020; Realo et al., 2015, 2017), but it has not been used for the present purpose.

### 2.2 | Measures

#### 2.2.1 | Munich Chronotype Questionnaire (MCTQ)

The Estonian version (Allebrandt et al., 2010) of the MCTQ by Roenneberg and his colleagues (2003) was used in this study. The questionnaire contains 17 items.

To quantify chronotype, a single-phase marker—mid-sleep on free days (MSF)—can be extracted from the questionnaire. It is the half-way point between sleep-onset (the time when someone falls asleep) and sleep-end (the wake-up time) on free days. Similar to earlier studies (van der Vinne et al., 2014; Wittmann et al., 2010), we corrected MSF for sleep-debt accumulated during the workweek ($MSF_{sc}$) when one's sleep duration on free days was greater than on work days and used the following formula: $MSF_{sc} = MSF - \frac{(SD_{free} - SD_{work})}{2}$, where MSF equals mid-sleep on free days, $SD_{free}$ equals sleep duration on free days, and $SD_{week}$ equals sleep duration on workdays. It can only be computed when no alarm clock is used to get out of bed. Therefore, we excluded participants who used an alarm clock on their free days.[2] In all following analyses, the mid-sleep corrected for sleep debt score ($MSF_{sc}$) was used as a marker for chronotype with higher scores indicating later chronotypes. In our study, chronotype roughly followed a normal distribution (skewness = .56, kurtosis = 1.10), suggesting that few people showed extremely early or late chronotypes. The mean score of $MSF_{sc}$ was 3.72 (*SD* = 1.18), ranging from −0.42 to 9.79 with higher scores indicating later chronotype. A negative score indicates that someone's mid-sleep time on free days was before midnight (i.e., the person must have gone to bed quite early in the evening).

#### 2.2.2 | NEO-PI-3

Personality traits were measured with the Estonian version of the NEO Personality Inventory-3 (NEO-PI-3; McCrae et al., 2005), which is a marginally modified version of the Estonian NEO-PI-R questionnaire (Costa & McCrae, 1992; Kallasmaa et al., 2000). The NEO-PI-3 consists of 240 items that measure five broad factors—Neuroticism, Extraversion, Openness to Experience (Openness), Agreeableness, and

Conscientiousness. Each of the five factors consists of six facets, resulting in a total of 30 facets. Each facet is measured by eight items, and items are answered on a five-point Likert-like scale, ranging from 0 *(strongly disagree)* to 4 *(strongly agree)*. Cronbach alphas of the domain and facet scales both in self- and informant-reports are shown in Supporting Information (Table S2). Self- and informant reports of the NEO-PI-3 personality traits correlated with each other in the expected magnitude (Connolly et al., 2007): Pearson $r$ values, all significant at $p < .001$, were as follows: Neuroticism = .51 (95% CI [.48, .54]), Extraversion = .66 (95% CI [.64, .68]), Openness = .61 (95% CI [.89, .63]), Agreeableness = .44 (95% CI [.41, .47]), and Conscientiousness = .51 (95% CI [.48, .54]). For participants with data available for both types of ratings (2,356; 93.68%), a mean score of self-and informant ratings was used in all analyses because multimethod assessments are seen as optimal in personality research and informant reports are an ideal complement to self-reports (Vazire, 2006). We used only self-reports for 131 (5.21%) participants and only informant-reports for 27 (1.07%). In order to validate our findings, we also conducted the analyses separately for self- and informant reports. The results are given in Tables S3 to S8 of the Supporting Information. Descriptive statistics (i.e., mean scores, standard deviations, and Cronbach alphas) of the five NEO-PI-3 domain and 30 facet scales separately for self- and informant reports are given in Table S2.

### 2.2.3 | Genetic correlations

We used the Atlas of GWAS Summary Statistics (https://atlas.ctglab.nl/) to compute genetic correlations between personality domains and morningness–eveningness. GWAS atlas is a comprehensive database of publicly available GWAS summary statistics (Bulik-Sullivan et al., 2015).

We selected the GWAS with the largest sample size per trait. The GWAS of morningness–eveningness (ID# 4294) was from the UK Biobank and consisted of 449,732 participants who categorized them as morning or evening people on a four-point scale (Jones et al., 2019). We used the GWAS of univariate Neuroticism (ID# 4321, $N = 523{,}783$) from the UK Biobank (Baselmans et al., 2019), which measured Neuroticism with the NEO Five Factor Inventory (NEO-FFI; Costa & McCrae, 1992). Extraversion (ID# 33) was harmonized with an Item Response Theory analysis on 63,661 individuals from a meta-analysis of the Genetics of Personality Consortium (van den Berg et al., 2016). Openness (ID# 29), Agreeableness (ID# 30), and Conscientiousness (ID# 31) were measured with the NEO-FFI (Costa & McCrae, 1992) and trained on 17,375 individuals using a meta-analysis of studies from different countries (de Moor et al., 2012). Agreeableness (de Moor et al., 2012; ID# 30) did not meet the criteria for genetic correlations as defined by GWAS atlas, but we nevertheless used harmonized summary statistics of Agreeableness of the same study from the GWAS Catalog (https://www.ebi.ac.uk/gwas/studies/GCST006329) as it was the only study with GWAS summary statistics available. Morningess–eveningness on LD Hub was derived from the GWAS by Jones et al. (2019) with only participants from the UK Biobank and not 23andMe.

### 2.2.4 | Polygenic scores

Genotyping was performed using different platforms (Global Screening Array, HumanCoreExome, HumanOmniExpress, and 370K). The imputed SNPs were filtered in Plink 1.9 (Chang et al., 2015), keeping SNPs that had (a) unique names, (b) only ACTG, and (c) MAF > .01. PGS software PRSice 2.2.6 (Euesden et al., 2015) excluded further ambiguous variants, resulting in 6,609,011 variants available for polygenic scoring. We used the data of 3,608 participants with personality and genotyping data, but occasional missing MCTQ data, to calculate 20 principal components with Plink 1.9. We standardized the PGSs so that they were more comparable with each other, with a mean of 0 and standard deviation of 1.

*PGS for morningness–eveningness*

The PGS for morningness–eveningness was trained on morningness–eveningness GWAS results (Jones et al., 2019) and based on 449,734 participants from the UK biobank and 248,098 participants from 23andMe using a four-scale item of morningness–eveningness ("Definitely a 'morning' person", "More a 'morning' than 'evening' person," "More an 'evening' than a 'morning' person," "Definitely an 'evening' person"). A higher score indicates greater tendency toward morningness.

*PGS parameters*

We used $p = 1$ cutoff and PRSice default clumping criteria ($r^2$ threshold for clumping = .1; clumping distance = 250 kb from both sides) for morningness–eveningness. INFO criterion was set to >.90. After matching with available variants in the data and clumping, the PGS for morningness–eveningness was based on 2,298 variants.

To perform a sensitivity analysis, we also used a genome-wide $p$-value cutoff of $p = 5 \times 10^{-8}$, as well as PRSice default clumping criteria ($r^2$ threshold for clumping = .1; clumping distance = 250 kb from both sides). The PGS was based on 139 variants.

## 2.3 | Procedure

The details of recruitment and data collection are explained in the cohort profile of the Estonian Biobank (Leitsalu et al., 2014). A part of the Estonian Biobank cohort has been followed up longitudinally, but the data utilized in this paper are cross-sectional.

Data collection took place between 2007 and 2014. Most participants (2,217; 88.15%) filled out the MCTQ and the NEO-PI-3 in the same year, 247 (9.82%) of the participants filled out the questionnaires within a difference of one year, 31 (1.23%) within two years, and remaining participants (11) within three to seven years. Over half of participants (1,530; 60.83%) completed the MCTQ between November and January (winter; average daylight seven hours), 594 (23.62%) had either filled it in between February and April or August and October (spring/fall; average daylight 12 hr), and 391 (15.55%) completed the questionnaire between May and July (summer; average daylight 17.5 hr).

## 2.4 | Statistical analyses

### 2.4.1 | Regressing chronotype on personality traits and facets

We performed a series of hierarchical regression analyses to regress chronotype ($MSF_{sc}$) on personality when controlling for sociodemographic variables and seasonality. In all analyses, two blocks of variables were regressed on chronotype: (a) FFM personality traits (either domains or facets) and (b) participant demographics (age, gender, and educational level) as well as the season during which the MCTQ was completed (winter, spring/fall, and summer). Basic education and winter were defined as the reference categories for education and season. Enter method was used for both blocks and all variables within a block were entered simultaneously. The assumptions for multiple regression analyses described by Williams et al. (2013) were met.

### 2.4.2 | Genetic correlations

We estimated genetic correlations through GWAS Atlas' own interface using linkage disequilibrium (LD)-score regression (Bulik-Sullivan et al., 2015).[3] For Agreeableness, we also used LD-score regression on LD Hub's interface (http://ldsc.broadinstitute.org/). LD-score regressions estimate co-heritability in a remarkably robust way (Harden & Koellinger, 2020).

### 2.4.3 | Polygenic score prediction of morningness–eveningness

We used R 3.6.1 for the analyses. First, we examined how much variance the PGS for morningness–eveningness explained in $MSF_{sc}$. Second, we predicted phenotypic NEO-PI-3 personality domains, facets, and nuances from the PGS for morningness–eveningness in separate analyses. In all analyses, the following variables were included in the model as independent variables: the chip (genotyping platform), age, gender, and education of the participant, the season when they completed the MCTQ, the 20 principal components as described above, and lastly, the PGS for morningness–eveningness.

### 2.4.4 | Adjusting the analyses for the false discovery rate

Due to the large number of tests undertaken, we adjusted the *p*-values of the hierarchical regression analyses and the polygenic score analyses retrospectively for the false discovery rate (Benjamini & Hochberg, 1995). We only report the adjusted *p*-values in the results section.

## 3 | RESULTS

## 3.1 | Preliminary and validation analyses

### 3.1.1 | The effect of seasonal variation on chronotype

A one-way between-subjects analysis of variance (ANOVA) was carried out to compare the effect of seasonal variation on $MSF_{sc}$. The season when the MCTQ was completed had a significant effect on $MSF_{sc}$, $F(2, 2{,}176) = 4.91$, $p = .007$, $\eta^2 = .005$. Post hoc comparisons using the Tukey HSD test indicated that the mean $MSF_{sc}$ score in winter ($M = 3.68$, $SD = 1.18$) was significantly lower than in summer ($M = 3.89$, $SD = 1.68$) at $p = .005$; 95% CI of the difference [−.37, −.05], indicating that people who completed the MCTQ in summer had later chronotypes than those who completed it in winter. There were no statistically significant differences in $MSF_{sc}$ between participants who completed the MCTQ in spring/fall ($M = 3.71$, $SD = 1.18$) versus those who filled it in either in winter or summer; 95% CIs of the difference [−.11, .16; −.37, −.00].

### 3.1.2 | Development of a weighted personality item score (polypersonality score)

We used the glmnet package (Friedman et al., 2021) in R 3.6.1 to identify personality items across all domains and facets that would best predict chronotype. We used a LASSO regression analysis to create weights for the personality items. Those items that were not significantly related to chronotype were given a weight of zero. In this model, we included all 240 personality items after regressing these traits on age, gender, education, and season. This method has been previously used to summarize personality, cognition, and brain effects on health outcomes (Benning et al., 2005; Vainik et al., 2018).

The model identified 23 personality items that best predicted chronotype. The relevant items and their labels, the facet to which they belong, and which weight they were given are listed in Table S9. The item that was most strongly related to $MSF_{sc}$ belongs to the C5: Self-discipline facet scale, "I waste a lot of time before settling down to work" (#55, reverse coded) which was related to an earlier chronotype. Several items from C4: Achievement-striving was also strongly related to $MSF_{sc}$ with people who consider themselves as somewhat "workaholic" typically exhibiting a lower $MSF_{sc}$ score. Fifteen items belonged to facets of Extraversion and Openness which were all related with going to and getting out of bed later. An additional six items were items of Agreeableness and Conscientiousness facets which were related to an earlier chronotype.

The relevant personality items were given a weight, which were added to a score (Polypersonality score). In order to avoid overfitting, we re-estimated the weights for each 90% subset of the sample and applied it to the left out 10% subset of the data. We then repeated this for all 90%–10% sets of the participants.

#### 3.1.3 | Predictive validity of the morningness–eveningness PGS

The PGS for morningness–eveningness predicted phenotypic $MSF_{sc}$ at $p < .001$ with a standardized regression coefficient of −.12 (as mentioned above, the PGS was trained on morningness–eveningness which is why the correlation is negative). Overall, the model explained 33.17% of the variance in $MSF_{sc}$, $f^2 = .52$. However, adding the PGS for chronotype to the initial model containing the 20 principal components and sociodemographic variables only increased the explained variance by 0.91%. When we used a cutoff point of $p = 5 \times 10^{-8}$, the standardized regression coefficient was −.07 ($p = .005$) and incremental $R^2$ was 0.23%, $f^2 = .50$.

### 3.2 | Associations between the FFM personality traits and chronotype

#### 3.2.1 | NEO-PI-3 domains

Extraversion, Openness, Agreeableness, and Conscientiousness were all significantly correlated with $MSF_{sc}$ at $p < .001$. $MSF_{sc}$ was most strongly and positively correlated with Openness ($r = .33$) and Extraversion ($r = .25$), meaning that people with later chronotypes had higher scores of Openness and Extraversion. The negative correlations of $MSF_{sc}$ with Agreeableness ($r = -.16$) and Conscientiousness ($r = -.16$) were smaller in size but still significant at $p < .001$, indicating that people with later chronotypes were less agreeable and conscientious. Neuroticism was the only personality domain that was not significantly correlated with $MSF_{sc}$. All bivariate correlations between chronotype ($MSF_{sc}$) and the NEO-PI-3 domain scores are given in Table 1.

Next, we conducted a hierarchical linear regression analysis to find out whether the relationships between $MSF_{sc}$ and the FFM domains remained significant after controlling for sociodemographic variables and season of completing MCTQ. First, a block with the NEO-PI-3 domain scores was entered, which explained 16.14% of the variance, $f^2 = .20$. When the second block of variables (i.e., the sociodemographic variables and season) was added to the regression model, the adjusted $R^2$ increased by 18.89% compared with Block 1, $f^2 = .55$. Table 2 gives an overview of the model, including regression coefficients with confidence intervals, standardized regression coefficients ($\beta$), and $t$-test statistics for the variables. Adjusted $R^2$, $F$-statistics, and effect sizes for each block in the hierarchical regression analyses are also presented.

In the first model, Extraversion, Openness, Agreeableness, and Conscientiousness predicted $MSF_{sc}$ at $p < .001$. Neuroticism was not a significant predictor of $MSF_{sc}$. When adding sociodemographics and seasonality to the model, later chronotype was significantly associated with lower scores in Conscientiousness ($\beta = -.15$; $p < .001$) and higher scores in Openness ($\beta = .12$; $p < .001$). Overall, age was the strongest predictor of chronotype ($\beta = -.48$, $p < .001$), and higher levels of education (secondary education: $\beta = .10$; $p = .034$ and higher education: $\beta = .16$; $p < .001$) were related to later chronotypes. All nine variables altogether explained 35.03% of the variance in $MSF_{sc}$.

#### 3.2.2 | NEO-PI-3 facets

On the facet level, 22 correlations out of 30 between $MSF_{sc}$ and NEO- PI-3 facet scales were significant at the level of $p < .05$. $MSF_{sc}$ was positively correlated at $p < .05$ with all facets of Extraversion and Openness, and a single facet of Neuroticism (N5: Impulsiveness). Five facets of Conscientiousness (C1: Competence, C2: Order, C3: Dutifulness, C5: Deliberation, and C6: Deliberation) and four facets of Agreeableness (A2: Straightforwardness, A4: Compliance, A5: Modesty, and A6: Tender-mindedness) were negatively correlated with $MSF_{sc}$ at $p < .05$. $MSF_{sc}$ was most strongly (.30 or above) correlated with E5: Excitement-seeking ($r = .39$) and O1: Openness to Fantasy ($r = .34$) at $p < .001$ (see Table 1).

**TABLE 1** Bivariate correlations of chronotype ($MSF_{sc}$) with the NEO-PI-3 domain and facet scores

| | $MSF_{sc}$ |
|---|---|
| **NEO-PI-3 domains** | |
| Neuroticism | .00 [−.04, .04] |
| Extraversion | **.25*** [.21, .29]** |
| Openness to Experience | **.33*** [.29, .37]** |
| Agreeableness | **−.16*** [−.20, −.11]** |
| Conscientiousness | **−.16*** [−.20, −.12]** |
| **NEO-PI-3 facets** | |
| *Neuroticism* | |
| N1: Anxiety | −.04 [−.08, .00] |
| N2: Angry hostility | −.01 [−.05, .04] |
| N3: Depression | −.02 [−.07, .02] |
| N4: Self-conscientiousness | −.04 [−.08, .00] |
| N5: Impulsiveness | **.13*** [.08, .17]** |
| N6: Vulnerability to stress | .00 [−.04, .04] |
| *Extraversion* | |
| E1: Warmth | **.10*** [.06, .14]** |
| E2: Gregariousness | **.20*** [.16, .24]** |
| E3: Assertiveness | **.12*** [.08, .16]** |
| E4: Activity | **.10*** [.06, .14]** |
| E5: Excitement-seeking | **.39*** [.36, .43]** |
| E6: Positive emotions | **.22*** [.18, .26]** |
| *Openness to Experience* | |
| O1: Openness to fantasy | **.34*** [.30, .38]** |
| O2: Openness to aesthetics | **.10*** [.06, .14]** |
| O3: Openness to feelings | **.23*** [.19, .27]** |
| O4: Openness to actions | **.26*** [.22, .30]** |
| O5: Openness to ideas | **.23*** [.19, .27]** |
| O6: Openness to values | **.31*** [.27, .35]** |
| *Agreeableness* | |
| A1: Trust | .02 [−.02, .07] |
| A2: Straightforwardness | **−.08*** [−.13, −.04]** |
| A3: Altruism | −.00 [−.05, .04] |
| A4: Compliance | **−.17*** [−.21, −.12]** |
| A5: Modesty | **−.24*** [−.28, −.20]** |
| A6: Tendermindedness | **−.16*** [−.20, −.12]** |
| *Conscientiousness* | |
| C1: Competence | **−.07** [−.11, −.03]** |
| C2: Order | **−.11*** [−.15, −.07]** |
| C3: Dutifulness | **−.20*** [−.24, −.16]** |
| C4: Achievement striving | −.03 [−.08, .01] |
| C5: Self-discipline | **−.16*** [−.20, −.12]** |
| C6: Deliberation | **−.19*** [−.23, −.15]** |

*Note:* $MSF_{sc}$ = mid-sleep corrected for sleep debt (chronotype) as measured with the Munich Chronotype Questionnaire (MCTQ); NEO-PI-3 = The NEO Personality Inventory-3 (self-and informant reports are combined). 95% confidence intervals are included in parentheses. Correlations in bold are significant at $p < .05$. $p$-values were adjusted for the false discovery rate.
$^{**}p < .01$; $^{***}p < .001$.

Next, we conducted a hierarchical linear regression analysis as above, with the only difference being that the NEO-PI-3 facet scales were added to the model, instead of the domain scores. Table S10 reports the results of the hierarchical regression analysis. All 34 variables explained 37.05% of the variance in $MSF_{sc}$. The adjusted $R^2$ increased by 11.41% with Block 1 (i.e., 30 facet scores), when the Block 2 variables (age, gender, education, and season) were added to the regression model, $f^2 = .62$. In the first model, ten facets were significant predictors of $MSF_{sc}$. However, when sociodemographic variables and season were added to the model, only younger age ($\beta = -.45$; $p < .001$), higher education ($\beta = .15$; $p < .001$), higher E5: Excitement-seeking ($\beta = .13$; $p < .001$), lower C5: Self-discipline ($\beta = -.10$; $p = .007$) and higher A2: Straightforwardness ($\beta = .10$; $p < .001$) made a significant contribution to the prediction of later chronotype. These results suggest it is younger, more educated as well as more straightforward and excitement-seeking, yet less self-disciplined people, who are more likely to have later chronotypes.

### 3.2.3 | NEO-PI-3 nuances

Since we already regressed the NEO-PI-3 items on sociodemographic variables and season, we did not additionally adjust for them. Therefore, we simply correlated the Polypersonality score with $MSF_{sc}$. The correlation between the two variables was $r = .28$ ($p < .001$) which indicates that the Polypersonality score was able to explain 7.84% of the variance in $MSF_{sc}$.

## 3.3 | Genetic relationships

### 3.3.1 | Genetic correlations

We defined the genetic correlation as the proportion of common genetic variation that is shared by two phenotypes (Hartz et al., 2018). Table 3 gives an overview of the genetic correlations between morningness–eveningness and the FFM personality domains. Morningness–eveningness was

**TABLE 2** Hierarchical linear regressions examining the influence of the NEO-PI-3 personality domains (combined self- and informant-ratings) on chronotype ($MSF_{sc}$) after controlling for age, gender, education, and season of completing the MCTQ

| | Model 1 | | | | Model 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | *b* [CI] | *β* | *t* | *p* | *b* [CI] | *β* | *t* | *p* |
| *Intercept* | 3.78 [3.15, 4.41] | | 11.72 | <.001 | 5.42 [4.75, 6.09] | | 15.88 | <.001 |
| *Block 1: NEO-PI-3 Domains* | | | | | | | | |
| Neuroticism | 0.00 [0.00, 0.00] | −.03 | −1.42 | .156 | 0.00 [0.00, 0.00] | −.05 | −2.19 | .052 |
| Extraversion | 0.01 [0.00, 0.01] | .11 | 4.39 | <.001 | 0.00 [0.00, 0.00] | .04 | 1.86 | .098 |
| Openness to Experience | 0.02 [0.01, 0.02] | .27 | 11.56 | <.001 | 0.01 [0.00, 0.01] | .12 | 5.64 | <.001 |
| Agreeableness | −0.01 [−0.01, 0.00] | −.11 | −5.21 | <.001 | 0.00 [0.00, 0.00] | −.01 | −0.76 | .920 |
| Conscientiousness | −0.01 [−0.01, −0.01] | −.18 | −8.27 | <.001 | −0.01 [−0.01, −0.01] | −.15 | −7.55 | <.001 |
| *Block 2: Sociodemographics and Season* | | | | | | | | |
| Age | | | | | −0.03 [−0.04, −0.03] | −.48 | −24.67 | <.001 |
| Gender | | | | | −0.03 [−0.12, 0.06] | −.01 | −0.64 | .524 |
| *Education* | | | | | | | | |
| Secondary | | | | | 0.23 [.04, .42] | .10 | 2.43 | .034 |
| Higher | | | | | 0.37 [.18, .56] | .16 | 3.86 | <.001 |
| *Season* | | | | | | | | |
| Spring/Fall | | | | | −0.07 [−0.16, 0.03] | −.03 | −1.38 | .204 |
| Summer | | | | | −0.09 [−0.20, 0.03] | −.03 | −1.51 | .181 |
| Adjusted $R^2$ | | | .161 | | | | .350 | |
| F for Change in $R^2$ | | | 84.82 | <.001 | | | 106.21 | <.001 |
| Effect size $f^2$ | | | .20 | | | | .55 | |

*Note:* NEO-PI-3 = The NEO Personality Inventory-3; CI = 95% confidence intervals; Gender: 0 = female; 1 = male; education: basic education = reference category, Season = the season of completing the Munich Chronotype Questionnaire (MCTQ), winter = reference category. *p*-values were adjusted for the false discovery rate.

**TABLE 3** Genetic correlation estimates of morningness-eveningness and the FFM personality domains from GWAS

| | Morningness-eveningness | | |
|---|---|---|---|
| | $r_g$ | *SE* | *p* |
| Neuroticism | −.02 | .03 | .582 |
| Extraversion | −.02 | .05 | .693 |
| Openness | −.24 | .07 | <.001 |
| Agreeableness | .01 | .06 | .837 |
| Conscientiousness | .31 | .09 | <.001 |

Abbreviations: FFM = Five factor model of personality; GWAS = genome-wide association studies; $r_g$ = genetic correlation; *SE* = standard error.

significantly genetically correlated with Openness ($r_g = -.24$, $p < .001$) and Conscientiousness ($r_g = .31$, $p < .001$).

### 3.3.2 | Regressing phenotypic FFM personality traits on the PGS for morningness–eveningness

Finally, we regressed all NEO-PI-3 personality domains, facets, and nuances (i.e., the Polypersonality score) on the PGS for morningness–eveningness using a series of multiple regression analyses (see Table 4). The results for the PGS with a cutoff of $p = 5 \times 10^{-8}$ are reported in Table S11 of the Supporting Information.

The PGS for morningness–eveningness did not significantly predict any phenotypic NEO-PI-3 personality domain or facet. However, it significantly predicted the Polypersonality score ($p < .001$; $f^2 = .03$) with a standardized regression coefficient of −.02, explaining 0.71% of the variance of the Polypersonality score. Our sensitivity analysis showed that when a cut-off point of $p = 5 \times 10^{-8}$ was used, the PGS was no longer able to significantly predict any component of the FFM personality hierarchy.

## 4 | DISCUSSION

This study examined the relationships between chronotype and the FFM personality traits at the domain, facet, and item level in a large sample of Estonian adults. Our results showed that phenotypic scores of personality and chronotype were related to each other on all three levels of the personality hierarchy. We also found that morningness–eveningness and personality were significantly genetically correlated with

 

**TABLE 4** Standardized regression coefficients of the polygenic score (PGS) for morningness–eveningness predicting the NEO-PI-3 domain and facet scores, and polypersonality score while controlling for the 20 principal components and sociodemographic variables

| | Regression coefficient | $p$ | Amount of explained variance |
|---|---|---|---|
| *Neuroticism* | .27 | .673 | 0.000 |
| N1: Anxiety | .14 | .568 | 0.000 |
| N2: Angry hostility | .05 | .890 | 0.000 |
| N3: Depression | .10 | .591 | 0.000 |
| N4: Self-Conscientiousness | .09 | .591 | 0.000 |
| N5: Impulsiveness | −.08 | .635 | 0.000 |
| N6: Vulnerability | −.01 | .951 | 0.000 |
| *Extraversion* | −.56 | .489 | 0.000 |
| E1: Warmth | −.17 | .220 | 0.001 |
| E2: Gregariousness | −.14 | .568 | 0.000 |
| E3: Assertiveness | −.01 | .951 | 0.000 |
| E4: Activity | .04 | .914 | 0.000 |
| E5: Excitement-seeking | −.20 | .180 | 0.001 |
| E6: Positive emotion | −.10 | .614 | 0.000 |
| *Openness to Experience* | −.71 | .236 | 0.001 |
| O1: Fantasy | −.14 | .523 | 0.001 |
| O2: Aesthetics | −.26 | .165 | 0.002 |
| O3: Feeling | .03 | .914 | 0.000 |
| O4: Actions | −.08 | .591 | 0.000 |
| O5: Ideas | −.31 | .090 | 0.003 |
| O6: Values | .03 | .890 | 0.000 |
| *Agreeableness* | −.02 | .951 | 0.000 |
| A1: Trust | −.09 | .591 | 0.000 |
| A2: Straightforwardness | −.12 | .568 | 0.000 |
| A3: Altruism | −.04 | .890 | 0.000 |
| A4: Compliance | −.01 | .951 | 0.000 |
| A5: Modesty | .21 | .165 | 0.002 |
| A6: Tender-mindedness | .02 | .914 | 0.000 |
| *Conscientiousness* | .42 | .489 | 0.000 |
| C1: Competence | −.02 | .914 | 0.000 |
| C2: Order | .14 | .568 | 0.000 |
| C3: Dutifulness | .00 | .972 | 0.000 |
| C4: Achievement striving | .12 | .568 | 0.000 |
| C5: Self-discipline | .22 | .165 | 0.002 |
| C6: Deliberation | −.03 | .914 | 0.000 |
| *Polypersonality score* | −.02 | <.001 | 0.007 |

*Note:* Polypersonality score = weighted personality-item score. The amount of variance explained was calculated as the difference between the adjusted $R^2$ of the baseline model and the model that included the morningenss–eveningness PGS. $p$-values were adjusted for the false discovery rate.

each other and that the PGS for morningness–eveningness significantly predicted the Polypersonality score at $p < .001$.

## 4.1 | The phenotypic relationships between chronotype and personality

Bivariate correlational analyses showed that chronotype was significantly related to all FFM personality domains besides Neuroticism at $p < .05$. Participants with higher levels of Extraversion and Openness had later chronotypes, whereas those with higher scores on Agreeableness and Conscientiousness had earlier chronotypes. Adding to previous mixed results about the role of gender in chronotype (Adan et al., 2012), we found that gender was not a significant predictor of chronotype. With sociodemographic factors and seasonality being controlled for, we found that participants who were low in Conscientiousness and high in Openness were more likely to have later chronotypes. These findings are in line with a study of a large sample of German adults by Randler and colleagues (2017) that also controlled for sociodemographic variables, which found Openness and Conscientiousness, but also Extraversion, to be a significant predictors of morningness–eveningness. In our model, Extraversion and Agreeableness were no longer statistically significant when adding sociodemographic variables and seasonality. As age was the strongest predictor of chronotype, it is quite likely that it impacted the relationships since it has been shown that Extraversion decreases during adulthood whereas Agreeableness increases (Soto et al., 2011).

One of the novel aspects of our study was analyzing the relationships between chronotype and the FFM personality traits at the facet level. Some of the facets (e.g., E5: Excitement-seeking and A2: Straightforwardness) correlated more strongly with chronotype than their respective domains (i.e., Extraversion and Agreeableness), suggesting that personality facets may indeed add important information about relationships between personality and various life outcomes in addition to broader personality traits (Mõttus, 2016; Paunonen & Ashton, 2001; Paunonen et al., 2003). When we controlled for sociodemographic variables and seasonality, we found that participants who were more excitement-seeking (E5) and straightforward (A2), but also with lower levels of self-discipline (C5) were more likely to have later chronotypes. For instance, people who score higher in E5: Excitement-seeking crave excitement and stimulation, and show a liking for bright colors and noisy environments (Costa & McCrae, 1992)—an environment you would typically find in a nightclub, which when visited, may encourage later bedtimes. People high in straightforwardness (A2), on the other hand, have been associated with being frank, sincere, and ingenuous (Costa & McCrae, 1992), which might make their presence more enjoyable for others. We can only speculate that people high in straightforwardness also tend to meet with others later during the day.

To further explore the personality–chronotype relationship, we included single personality items (or nuances) in our analysis as these have shown to sometimes be better predictors of consequential life outcomes than personality traits or facets (Vainik et al., 2015). Our model identified 23 NEO-PI-3 items were related with chronotype while controlling for sociodemographic variables and seasonality. These 23 items were given specific weights according to their importance and summed up to a Polypersonality score that would best predict chronotype. When we correlated the Polypersonality score with $MSF_{sc}$, the correlation between the two constructs was $r = .28$ ($p < .001$), which indicates that the Polypersonality score explained 7.84% of the variance in $MSF_{sc}$.

The item with the highest weight—"I waste a lot of time before settling to work" (#55)—belongs to the C5: Self-discipline facet scale. Participants who indicated that they would waste a lot of time before settling to work exhibited later chronotypes. The item with the second-highest weight in predicting chronotype was "I'm somewhat of a workaholic" (#230) which was part of C4: Achievement-striving. Participants who described themselves as workaholics were more likely to go to bed and wake up earlier.

### 4.2 | The possible pathways explaining phenotypic personality–chronotype relationships

What are the possible explanations for the personality–chronotype relationships? Even though our findings do not allow to say anything about the causality of the personality–chronotype relationship, it has been suggested that chronotype is also influenced by human behavior (Roenneberg et al., 2019). There are least two ways of how to interpret our results from the perspective of personality psychology. First, personality traits may influence chronotype through shaping people's preferences for various social activities and behaviors, which in turn, may influence what time people go to and get out of bed. It has been shown, for example, that less conscientious people more often engage in excessive alcohol use which typically happens on weekend nights (Parker & Williams, 2003). People high in E5: Excitement-seeking have been shown to also be high in sensation-seeking (Aluja et al., 2003), and are therefore more likely to engage in alcohol use and risky sexual behavior, including a higher frequency of one-night stands (Justus et al., 2000). Similar to chronotype, Openness has been found to reach its peak when adolescents are transitioning into young adulthood (Lüdtke et al., 2011; Vecchione et al., 2012). However, open individuals tend to feel younger than their chronological age, with this association growing stronger with increasing age (Stephan et al., 2012). People high in Openness continue to be curious during the life span and want to try out new things and go to new places (Sutin, 2015): they more frequently attend concerts (Nusbaum & Silvia, 2010), and spend more time in restaurants and bars (Mehl et al., 2006), with many of these are activities often happening in the evening. Thus, it is highly possible that people with certain personality traits (e.g., low Conscientiousness, high Openness etc.) are more likely to engage with certain social activities that keep them up later at night and sleeping until later in the morning.

The second possible pathway of how personality may influence chronotype is through active decisions people make regarding their sleep. Conscientious people, for instance, are more likely to be on time and not to oversleep (Jackson & Roberts, 2015), and might engage in sleeping patterns that help them to achieve those goals. They might get used to their sleeping patterns during the week so that they do not differ from each other so much on the weekend. That Conscientiousness and morningness–eveningness are related (see for example Lipnevich et al., 2017; Tsaousis, 2010) with each other, are highlighted by their similarity in relationships to health and mortality—people low in Conscientiousness and later chronotypes are more likely to die to younger (Friedman & Kern, 2014; Partonen, 2015). It may be then, that people high in Conscientiousness make deliberate decisions to go to bed earlier as part of a healthier lifestyle choices (cf. Bogg & Roberts, 2004). In fact, evidence suggests that people high in C5: Self-discipline participate in various health-promoting behaviors whereas they avoid or reduce behaviors that are harmful for their health (Weiss & Costa, 2005). Thus, people high in self-discipline might engage in similar sleeping patterns during the weekend, or other free days, because of their weekday routine.

### 4.3 | Genetic mechanisms underlying the relationships between personality and morningness–eveningness

In addition to the pathways explained above, it is also possible that personality and chronotype might be related because of their shared genetic etiology. The genetic correlations between morningness–eveningness and the FFM personality domains showed that Conscientiousness was related to morningness whereas Openness was related to eveningness. This is consistent with the results of our hierarchical regression analysis when regressing phenotypic personality on chronotype, even though the GWAS did not come from the Estonian biobank, were trained on morningness–eveningness and different personality questionnaires.

To further explore the genetic mechanisms between personality and chronotype within the Estonian biobank participants, we used a PGS for morningness–eveningness. The PGS for morningness–eveningness explained 0.91% of variance in $MSF_{sc}$, even though it was trained on diurnal preferences (i.e., morningness–eveningness) and not on chronotype as conceptualized and measured by the MCTQ. The PGS of morningness–eveningness was able to significantly predict the item-level Polypersonality score, explaining 0.71% of its variance, indicating that specific personality items might be related the most with morningness–eveningness, even at a genetic level. However, when employing a different *p*-value cutoff point of $p = 5x10^{-8}$ which used far fewer genetic variants, the relationship was no longer significant. This suggests that restricting the list of SNPs to GWAS significant variants reduces the predictive value of PGSs (Lamri et al., 2020).

## 4.4 | Possible implications of the study

One of the personality traits that showed significant relationships with chronotype at different all three levels of personality was a facet of Conscientiousness, C5: Self-discipline. In previous research, low levels of self-control, which has been used synonymously with self-discipline (Duckworth, 2011), has been linked to eveningness (Digdon & Howell, 2008). By contrast, high self-control is a predictor of many positive outcomes such as good physical health, lower levels of substance dependence, and fewer criminal offending outcomes 32 years after birth (Moffitt et al., 2011). Interestingly, although personality traits are mostly stable over time, self-control interventions have shown promise in enhancing one's level of self-control (Muraven, 2010). This might be particularly important, given that the tendency of morning people to be future-oriented is mediated by self-control (Milfont & Schwarzenthal, 2014). Thus, evening people could become more future-orientated and learn to value the importance of regular sleeping patterns in the long-term. It is known that chronotype can also be altered by social or professional demands such as having a familiy or work (Abbott et al., 2017; Leonhard & Randler, 2009), suggesting that it might be possible to change one's chronotype in a more intentional way. Ideally work hours would be adapted to one's chronotype (Petru et al., 2005), but if life circumstances do not permit such flexibility, humans could learn to apply strategies that facilitate them to go to bed at earlier hours. Turning off the lights earlier might also influence the timing of the release of melatonin as circadian rhythms are heavily influenced by light (Duffy et al., 1996). Thus, evening people would be ready to fall asleep at a more appropriate time.

## 4.5 | Limitations, conclusions, and future research

Of course, our study does not come without its limitations. We assessed chronotype using the MCTQ (Roenneberg et al., 2003) which uses mid-sleep on free days corrected for sleep debt as an indicator of chronotype. This score is only computable for people who do not use an alarm clock on weekends. Thus, we had to exclude 336 participants who differed from the included participants in terms of age, education, and personality domains (see Table S1) which might have influenced our results. Furthermore, we used chronotype for the phenotypic analyses, but morningness–eveningness for the genetic analyses. The two constructs are highly related with each other (Zavada et al., 2005), but do not measure the same (Roenneberg, 2015). However, we showed that the morningness–eveningness PGS regressed on $MSF_{sc}$, indicating that both morningness–eveningness and chronotype underly similar genetic mechanisms.

This study has contributed to a more thorough understanding of the relationship between personality and chronotype/morningness–eveningness. To the best of our knowledge, our study is the first to explore personality facets and items as predictors of chronotype. The trait- and facet models showed distinctive features in predicting chronotype. For example, A2: Straightforwardness, a facet of Agreeableness, and E5: Excitement-seeking, a facet of Extraversion, significantly predicted chronotype in the facet model even though Agreeableness and Extraversion did not predict chronotype in the trait model. As the PGS of morningness–eveningness was only able to regress on the Polypersonality score, the Polypersonality score seems to be related the most with morningness–eveningness. Future research should focus on the generalizability of the findings around the globe in places with different latitudes using large scale adult samples. Longitudinal studies are needed as they can help to understand the direction of causality between personality and chronotype by observing the temporal order of events. Future studies should investigate whether the personality items that were significant predictors of $MSF_{sc}$ in our analysis also predict $MSF_{sc}$ in other data sets. A more practical implication of our study might be to enhance self-discipline to promote better health in later chronotypes.

In sum, we showed in this study how personality might influence chronotype via two mechanisms that aligned with our results—people with certain personality traits, such as Openness, choose activities that encourage certain bedtimes, or that people high in Conscientiousness and especially in C5: Self-discipline, may actively choose their bedtimes so that they can better follow their (health-related) goals. However, chronotype could also influence personality or the two constructs might mutually influence each other. The latter is supported by our findings that indicate a clear genetic relationship between morningness–eveningness and personality. Subsequent studies will be necessary to better understand the shared genetic mechanisms between the two constructs as well as the causality of their relationships.

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## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## ETHICS STATEMENT

This research was approved by the Research Ethics Committee of the University of Tartu (approvals: 236/M-29, 14 May 2014; 206/T-4, 22 Aug 2011; 170/T-38, 28 April 2008; 166/T-21, 17 Dec 2007). Secondary data analysis of the Estonian Biobank data was approved by the Ethics Committee of the Department of Psychology at the University of Warwick on 19 November 2018.

## DATA AVAILABILITY STATEMENT

The pseudodata was created with the synthpop package in R. R scripts, and SPSS Syntax can be found here. If you want to get access to the real data, you need to apply for permission from the Estonian Biobank (https://genomics.ut.ee/en/biobank.ee/data-access). We preregistered neither our study nor the analysis.

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## ENDNOTES

[1] The correlation is negative since a high score in the MEQ means a higher morningness tendency.

[2] Three hundred and thirty-six participants were excluded from the chronotype analysis since they had indicated to use an alarm clock on free days. The mean age of the excluded participants was 47.67 (*SD* = 15.35) and 200 (59.52%) were female. A more detailed description of the excluded and included participants can be found in Table S1 of the Supporting Information.

[3] https://atlas.ctglab.nl/documentation#1

## REFERENCES

Abbott, S. M., Reid, K. J., & Zee, P. C. (2017). Circadian disorders of the sleep-wake cycle. In M. H. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and practice of sleep medicine* (Vol. *6*, pp. 414–423.e415). Elsevier.

Adan, A., Archer, S. N., Paz Hidalgo, M., Di Milia, L., Natale, V., & Randler, C. (2012). Circadian typology: A comprehensive review. *Chronobiology International*, *29*(9), 1153–1175. https://doi.org/10.3109/07420528.2012.719971

Allebrandt, K. V., Teder-Laving, M., Akyol, M., Pichler, I., Müller-Myhsok, B., Pramstaller, P., Merrow, M., Meitinger, T., Metspalu, A., & Roenneberg, T. (2010). CLOCK gene variants associate with sleep duration in two independent populations. *Biological Psychiatry*, *67*(11), 1040–1047. https://doi.org/10.1016/j.biopsych.2009.12.026

Allebrandt, K. V., Teder-Laving, M., Kantermann, T., Peters, A., Campbell, H., Rudan, I., Wilson, J. F., Metspalu, A., & Roenneberg, T. (2014). Chronotype and sleep duration: The influence of season of assessment. *Chronobiology International*, *31*(5), 731–740. https://doi.org/10.3109/07420528.2014.901347

Aluja, A., Garcia, Ó., & Garcia, L. F. (2003). Relationships among extraversion, openness to experience, and sensation seeking. *Personality and Individual Differences*, *35*, 671–680. https://doi.org/10.1016/S0191-8869(02)00244-1

Barclay, N. L., Eley, T. C., Buysse, D. J., Archer, S. N., & Gregory, A. M. (2010). Diurnal preference and sleep quality: Same genes? A study of young adult twins. *Chronobiology International*, *27*(2), 278–296. https://doi.org/10.3109/07420521003663801

Baselmans, B. M. L., Jansen, R., Ip, H. F., van Dongen, J., Abdellaoui, A., van de Weijer, M. P., Bao, Y., Smart, M., Kumari, M., Willemsen, G., Hottenga, J.-J., Boomsma, D. I., de Geus, E. J. C., Nivard, M. G., & Bartels, M. (2019). Multivariate genome-wide analyses of the well-being spectrum. *Nature Genetics*, *51*(3), 445–451. https://doi.org/10.1038/s41588-018-0320-8

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological)*, *57*(1), 289–300.

Benning, S. D., Patrick, C. J., Blonigen, D. M., Hicks, B. M., & Iacono, W. G. (2005). Estimating facets of psychopathy from normal personality traits: A step toward community epidemiological investigations. *Assessment*, *12*(1), 3–18. https://doi.org/10.1177/1073191104271223

Bogg, T., & Roberts, B. W. (2004). Conscientiousness and health behaviors: A meta-analysis. *Psychological Bulletin*, *130*, 887–919.

Bulik-Sullivan, B., Finucane, H. K., Anttila, V., Gusev, A., Day, F. R., Loh, P.-R., Duncan, L., Perry, J. R. B., Patterson, N., Robinson, E. B., Daly, M. J., Price, A. L., & Neale, B. M. (2015). An atlas of genetic correlations across human diseases and traits. *Nature Genetics*, *47*(11), 1236–1241. https://doi.org/10.1038/ng.3406

Carciofo, R., Yang, J., Song, N., Du, F., & Zhang, K. (2016). Psychometric evaluation of chinese-language 44-item and 10-item Big Five Personality Inventories, including correlations with chronotype, mindfulness and mind wandering. *PLoS ONE*, *11*(2), 1–26. https://doi.org/10.1371/journal.pone.0149963

Chang, C. C., Chow, C. C., Tellier, L. C., Vattikuti, S., Purcell, S. M., & Lee, J. J. (2015). Second-generation PLINK: Rising to the challenge of larger and richer datasets. *Gigascience*, *4*(7), 1–16. https://doi.org/10.1186/s13742-015-0047-8

Choi, S. W., Heng, M. S. T., & O'Reilly, P. F. (2020). A guide to performing Polygenic Risk Score analyses. *Nature Protocols*, *15*, 2759–2772. https://doi.org/10.1101/416545

Connolly, J. J., Kavanagh, E. J., & Viswesvaran, C. (2007). The convergent validity between self and observer ratings of personality: A meta-analytic review. *International Journal of Selection and Assessment*, *15*(1), 110–117. https://doi.org/10.1111/j.1468-2389.2007.00371.x

Costa, P. T., Jr., & McCrae, R. R. (1992). *Revised NEO Personality Inventory (NEO PI-R) and NEO Five-Factor Inventory (NEO-FFI) professional manual*. Psychological Assessment Resources.

Czeisler, C. A., & Buxton, O. M. (2017). Human circadian timing system and sleep-wake regulation. In M. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and practice of sleep medicine* (6th ed., pp. 362–376.e365). Elsevier.

de Moor, M. H. M., Costa, P. T., Terracciano, A., Krueger, R. F., de Geus, E. J. C., Toshiko, T., Penninx, B. W. J. H., Esko, T., Madden, P. A. F., Derringer, J., Amin, N., Willemsen, G., Hottenga, J.-J., Distel, M. A., Uda, M., Sanna, S., Spinhoven, P., Hartman, C. A., Sullivan, P., … Boomsma, D. I. (2012). Meta-analysis of genome-wide association studies for personality. *Molecular Psychiatry*, *17*(3), 337–349. https://doi.org/10.1038/mp.2010.128

Digdon, N. L., & Howell, A. J. (2008). College students who have an eveningness preference report lower self-control and greater procrastination. *Chronobiology International*, *25*(6), 1029–1046. https://doi.org/10.1080/07420520802553671

Duckworth, A. L. (2011). The significance of self-control. *Proceedings of the National Academy of Sciences*, *108*(7), 2639–2640. https://doi.org/10.1073/pnas.1019725108

Duffy, J. F., Kronauer, R. E., & Czeisler, C. A. (1996). Phase-shifting human circadian rhythms: Influence of sleep timing, social contact and light exposure. *The Journal of Physiology*, *495*(1), 289–297. https://doi.org/10.1113/jphysiol.1996.sp021593

Duggan, K. A., Friedman, H. S., McDevitt, E. A., & Mednick, S. C. (2014). Personality and healthy sleep: The importance of conscientiousness and neuroticism. *PLoS ONE*, *9*(3), e90628. https://doi.org/10.1371/journal.pone.0090628

Euesden, J., Lewis, C. M., & O'Reilly, P. F. (2015). PRSice: Polygenic risk score software. *Bioinformatics*, *31*(9), 1466–1468. https://doi.org/10.1093/bioinformatics/btu848

Friedman, H. S., & Kern, M. L. (2014). Personality, well-being, and health. *Annual Review of Psychology*, *65*, 719–742. https://doi.org/10.1146/annurev-psych-010213-115123

Friedman, J., Hastie, T., Tibshirani, R., Simon, N., Narasimhan, B., & Qian, J. (2021). Package "glmnet". https://CRAN.R-project.org/package=glmnet

Gratten, J., Wray, N. R., Keller, M. C., & Visscher, P. M. (2014). Large-scale genomics unveils the genetic architecture of psychiatric disorders. *Nature Neuroscience*, *17*(6), 782–790. https://doi.org/10.1038/nn.3708

Hagger-Johnson, G. E., & Whiteman, M. C. (2007). Conscientiousness facets and health behaviors: A latent variable modeling approach. *Personality and Individual Differences*, *43*(5), 1235–1245. https://doi.org/10.1016/j.paid.2007.03.014

Harden, K. P., & Koellinger, P. D. (2020). Using genetics for social science. *Nature Human Behaviour*, *4*(6), 567–576. https://doi.org/10.1038/s41562-020-0862-5

Hartz, S. M., Horton, A. C., Hancock, D. B., Baker, T. B., Caporaso, N. E., Chen, L.-S., Hokanson, J. E., Lutz, S. M., Marazita, M. L., McNeil, D. W., Pato, C. N., Pato, M. T., Johnson, E. O., & Bierut, L. J. (2018). Genetic correlation between smoking behaviors and schizophrenia. *Schizophrenia Research*, *194*, 86–90. https://doi.org/10.1016/j.schres.2017.02.022

Hill, W. D., Weiss, A., Liewald, D. C., Davies, G., Porteous, D. J., Hayward, C., McIntosh, A. M., Gale, C. R., & Deary, I. J. (2019). Genetic contributions to two special factors of neuroticism are associated with affluence, higher intelligence, better health, and longer life. *Molecular Psychiatry*, *25*, 3034–3052. https://doi.org/10.1038/s41380-019-0387-3

Horne, J. A., & Östberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology*, *4*, 97–110.

Hur, Y.-M. (2007). Stability of genetic influence on morningness–eveningness: A cross-sectional examination of South Korean twins from preadolescence to young adulthood. *Journal of Sleep Research*, *16*, 17–23. https://doi.org/10.1111/j.1365-2869.2007.00562.x

Jackson, J. J., & Roberts, B. W. (2015). Conscientiousness. In T. A. Widiger (Ed.), *The Oxford handbook of the five factor model*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199352487.013

Jarnecke, M., & South, S. C. (2015). Behavior and molecular genetics of the five factor model. In T. A. Widiger (Ed.), *The Oxford handbook of the five factor model*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199352487.013.25

Jiménez, K. M., Pereira-Morales, A. J., & Forero, D. A. (2017). Higher scores in the extraversion personality trait are associated with a functional polymorphism in the PER3 gene in healthy subjects. *Chronobiology International*, *34*, 280–286.

Jones, S. E., Lane, J. M., Wood, A. R., van Hees, V. T., Tyrrell, J., Beaumont, R. N., & Weedon, M. N. (2019). Genome-wide association analyses of chronotype in 697,828 individuals provides new insights into circadian rhythms in humans and links to disease. *Nature Communications*, *10*(343), 1–11. https://doi.org/10.1038/s41467-018-08259-7

Jones, S. E., Tyrrell, J., Wood, A. R., Beaumont, R. N., Ruth, K. S., Tuke, M. A., Yaghootkar, H., Hu, Y., Teder-Laving, M., Hayward, C., Roenneberg, T., Wilson, J. F., Del Greco, F., Hicks, A. A., Shin, C., Yun, C.-H., Lee, S. K., Metspalu, A., Byrne, E. M., … Weedon, M. N. (2016). Genome-wide association analyses in 128,266 individuals identifies new morningness and sleep duration loci. *PLOS Genetics*, *12*(8), e1006125. https://doi.org/10.1371/journal.pgen.1006125

Justus, A. N., Finn, P. R., & Steinmetz, J. E. (2000). The influence of traits of disinhibition on the association between alcohol use and risky sexual behavior. *Alcoholism: Clinical and Experimental Research*, *24*(7), 1028–1035. https://doi.org/10.1111/j.1530-0277.2000.tb04646.x

Kallasmaa, T., Allik, J., Realo, A., & McCrae, R. R. (2000). The Estonian version of the NEO-PI-R: An examination of universal and culture-specific aspects of the Five-Factor Model. *European Journal of Personality*, *14*, 265–278. https://doi.org/10.1002/1099-0984(200005/06)14:3<265:AID-PER376>3.0.CO;2-B

Kantermann, T., & Eastman, C. I. (2018). Circadian phase, circadian period and chronotype are reproducible over months. *Chronobiology International*, *35*(2), 280–288. https://doi.org/10.1080/07420528.2017.1400979

Kantermann, T., Sung, H., & Burgess, H. J. (2015). Comparing the morningness-eveningness questionnaire and Munich chronotype questionnaire to the dim light melatonin onset. *Journal of Biological Rhythms*, *30*(5), 449–453. https://doi.org/10.1177/0748730415597520

Keller, L. K., Zöschg, S., Grünewald, B., Roenneberg, T., & Schulte-Körne, G. (2016). Chronotyp und Depression bei Jugendlichen—ein

Review. [Chronotype and depression in adolescents—A review]. *Zeitschrift für Kinder- und Jugendpsychiatrie und Psychotherapie*, *44*(2), 113–126. https://doi.org/10.1024/1422-4917/a000406

Kööts-Ausmees, L., Schmidt, M., Esko, T., Metspalu, A., Allik, J., & Realo, A. (2016). The role of the Five Factor personality traits in self-reported general health. *European Journal of Personality*, *30*(5), 492–504. https://doi.org/10.1002/per.2058

Koskenvuo, M., Hublin, C., Partinen, M., Heikkila, K., & Kaprio, J. (2007). Heritability of diurnal type: A nationwide study of 8753 adult twin pairs. *Journal of Sleep Research*, *16*, 156–162. https://doi.org/10.1111/j.1365-2869.2007.00580.x

Lamri, A., Mao, S., Desai, D., Gupta, M., Pare, G., & Anand, S. S. (2020). Fine-tuning of genome-wide polygenic risk scores and prediction of gestational diabetes in South Asian women. *Scientific Reports*, *10*(1), 8941. https://doi.org/10.1038/s41598-020-65360-y

Leitsalu, L., Haller, T., Esko, T., Tammesoo, M.-L., Alavere, H., Snieder, H., Perola, M., Ng, P. C., Mägi, R., Milani, L., Fischer, K., & Metspalu, A. (2014). Cohort profile: Estonian Biobank of the Estonian Genome Center, University of Tartu. *International Journal of Epidemiology*, *44*(4), 1137–1147. https://doi.org/10.1093/ije/dyt268

Leonhard, C., & Randler, C. (2009). In sync with the family: Children and partners influence the sleep-wake circadian rhythm and social habits of women. *Chronobiology International*, *26*(3), 510–525. https://doi.org/10.1080/07420520902821101

Lenneis, A., Das-Friebel, A., Singmann, H., Teder-Laving, M., Lemola, S., Wolke, D., Tang, N. K. Y., von Mühlenen, A., Allik, J., & Realo, A. (2020). Intraindividual variability and temporal stability of midsleep on free and workdays. *Journal of Biological Rhythms*, *36*(2), 169–184. https://doi.org/10.1177/0748730420974842

Lipnevich, A. A., Crede, M., Hahn, E., Spinath, F. M., Roberts, R. D., & Preckel, F. (2017). How distinctive are morningness and eveningness from the Big Five factors of personality? A meta-analytic investigation. *Journal of Personality and Social Psychology*, *112*(3), 491–509. https://doi.org/10.1037/pspp0000099

Lucassen, E. A., Zhao, X., Rother, K. I., Mattingly, M. S., Courville, A. B., de Jonge, L., Csako, G., & Cizza, G. (2013). Evening chronotype is associated with changes in eating behavior, more sleep apnea, and increased stress hormones in short sleeping obese individuals. *PLoS ONE*, *8*(3), 1–10. https://doi.org/10.1371/journal.pone.0056519

Lüdtke, O., Roberts, B. W., Trautwein, U., & Nagy, G. (2011). A random walk down university avenue: Life paths, life events, and personality trait change at the transition to university life. *Journal of Personality and Social Psychology*, *101*(3), 620–637. https://doi.org/10.1037/a0023743

McCrae, R. R. (2015). A more nuanced view of reliability: Specificity in the trait hierarchy. *Personality and Social Psychology Review*, *19*(2), 97–112. https://doi.org/10.1177/1088868314541857

McCrae, R. R., Costa, P. T., Hřebíčková, M., Urbánek, T., Martin, T. A., Oryol, V. E., Rukavishnikov, A. A., & Senin, I. G. (2004). Age differences in personality traits across cultures: Self-report and observer perspectives. *European Journal of Personality*, *18*(2), 143–157. https://doi.org/10.1002/per.510

McCrae, R. R., Costa, P. T. Jr, & Martin, T. A. (2005). The NEO-PI-3: A more readable revised NEO Personality Inventory. *Journal of Personality Assessment*, *84*, 261–270. https://doi.org/10.1207/s15327752jpa8403_05

Mehl, M. R., Gosling, S. D., & Pennebaker, J. W. (2006). Personality in its natural habitat: Manifestations and implicit folk theories of personality in daily life. *Journal of Personality and Social Psychology*, *90*(5), 862–877. https://doi.org/10.1037/0022-3514.90.5.862

Milfont, T. L., & Schwarzenthal, M. (2014). Explaining why larks are future-oriented and owls are present-oriented: Self-control mediates the chronotype-time perspective relationships. *Chronobiology International*, *31*(4), 581–588. https://doi.org/10.3109/07420528.2013.876428

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., Houts, R., Poulton, R., Roberts, B. W., Ross, S., Sears, M. R., Thomson, W. M., & Caspi, A. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences*, *108*(7), 2693–2698. https://doi.org/10.1073/pnas.1010076108

Mõttus, R. (2016). Towards more rigorous personality trait-outcome research. *European Journal of Personality*, *30*(4), 292–303. https://doi.org/10.1002/per.2041

Muraven, M. (2010). Building self-control strength: Practicing self-control leads to improved self-control performance. *Journal of Experimental Social Psychology*, *46*(2), 465–468. https://doi.org/10.1016/j.jesp.2009.12.011

Nagel, M., Jansen, P. R., Stringer, S., Watanabe, K., de Leeuw, C. A., Bryois, J., Savage, J. E., Hammerschlag, A. R., Skene, N. G., Muñoz-Manchado, A. B., White, T., Tiemeier, H., Linnarsson, S., Hjerling-Leffler, J., Polderman, T. J. C., Sullivan, P. F., van der Sluis, S., & Posthuma, D. (2018). Meta-analysis of genome-wide association studies for neuroticism in 449,484 individuals identifies novel genetic loci and pathways. *Nature Genetics*, *50*(7), 920–927. https://doi.org/10.1038/s41588-018-0151-7

Nusbaum, E. C., & Silvia, P. J. (2010). Shivers and timbres: Personality and the experience of chills from music. *Social Psychological and Personality Science*, *2*(2), 199–204. https://doi.org/10.1177/1948550610386810

Paine, S. J., Gander, P. H., & Travier, N. (2006). The epidemiology of morningness/eveningness: Influence of age, gender, ethnicity, and socioeconomic factors in adults (30–49 years). *Journal of Biological Rhythms*, *21*(1), 68–76. https://doi.org/10.1177/0748730405283154

Parker, H., & Williams, L. (2003). Intoxicated Weekends: Young adults' work hard–play hard lifestyles, public health and public disorder. *Drugs: Education, Prevention & Policy*, *10*(4), 345–367. https://doi.org/10.1080/0968763031000140200

Partonen, T. (2015). Chronotype and health outcomes. *Current Sleep Medicine Reports*, *1*(4), 205–211. https://doi.org/10.1007/s40675-015-0022-z

Paunonen, S. V., & Ashton, M. C. (2001). Big Five Factors and facets and the prediction of behavior. *Journal of Personality and Social Psychology*, *81*(3), 524–539. https://doi.org/10.1037/0022-3514.81.3.524

Paunonen, S. V., Haddock, G., Forsterling, F., & Keinonen, M. (2003). Broad versus narrow personality measures and the prediction of behavior across cultures. *European Journal of Personality*, *17*, 413–433.

Petru, R., Wittmann, M., Nowak, D., Birkholz, B., & Angerer, P. (2005). Effects of working permanent night shifts and two shifts on cognitive and psychomotor performance. *International Archives of Occupational and Environmental Health*, *78*(2), 109–116. https://doi.org/10.1007/s00420-004-0585-3

Rahafar, A., Mohamadpour, S., & Randler, C. (2018). Napping and morningness–eveningness. *Biological Rhythm Research*, *49*(6), 948–954. https://doi.org/10.1080/09291016.2018.1430491

Randler, C. (2008). Morningness–eveningness, sleep–wake variables and Big Five personality factors. *Personality and Individual Differences*, *45*(2), 191–196. https://doi.org/10.1016/j.paid.2008.03.007

Randler, C., Horzum, M. B., & Vollmer, C. (2014). Internet addiction and its relationship to chronotype and personality in a Turkish university student sample. *Social Science Computer Review*, *32*(4), 484–495. https://doi.org/10.1177/0894439313511055

Randler, C., & Rahafar, A. (2017). Latitude affects morningness–eveningness: Evidence for the environment hypothesis based on a systematic review. *Scientific Reports*, *7*, 1–6. https://doi.org/10.1038/srep39976

Randler, C., Schredl, M., & Göritz, A. S. (2017). Chronotype, sleep behavior, and the Big Five personality factors. *SAGE Open*, *7*(3), 215824401772832. https://doi.org/10.1177/2158244017728321

Realo, A., Teras, A., Kööts-Ausmees, L., Esko, T., Metspalu, A., & Allik, J. (2015). The relationship between the Five-Factor Model personality traits and peptic ulcer disease in a large population-based adult sample. *Scandinavian Journal of Psychology*, *56*, 693–699. https://doi.org/10.1111/sjop.12248

Realo, A., van der Most, P. J., Allik, J., Esko, T., Jeronimus, B. F., Kööts-Ausmees, L., Mõttus, R., Tropf, F. C., Snieder, H., & Ormel, J. (2017). SNP-based heritability estimates of common and specific variance in self- and informant-reported Neuroticism scales. *Journal of Personality*, *85*, 906–919. https://doi.org/10.1111/jopy.12297

Roenneberg, T. (2012). What is chronotype? *Sleep and Biological Rhythms*, *10*(2), 75–76. https://doi.org/10.1111/j.1479-8425.2012.00541.x

Roenneberg, T. (2015). Having trouble typing? What on earth is chronotype? *Journal of Biological Rhythms*, *30*(6), 487–491. https://doi.org/10.1177/0748730415603835

Roenneberg, T., Kuehnle, T., Juda, M., Kantermann, T., Allebrandt, K., Gordijn, M., & Merrow, M. (2007). Epidemiology of the human circadian clock. *Sleep Medicine Reviews*, *11*(6), 429–438. https://doi.org/10.1016/j.smrv.2007.07.005

Roenneberg, T., & Merrow, M. (2007). *Entrainment of the human circadian clock*. Paper presented at the Cold Spring Harbor Symposia on Quantitative Biology.

Roenneberg, T., Pilz, L. K., Zerbini, G., & Winnebeck, E. C. (2019). Chronotype and social jetlag: A (self-) critical review. *Biology*, *8*(3), 54. https://doi.org/10.3390/biology8030054

Roenneberg, T., Wirz-Justice, A., & Merrow, M. (2003). Life between clocks: Daily temporal patterns of human chronotypes. *Journal of Biological Rhythms*, *18*(1), 80–90. https://doi.org/10.1177/0748730402239679

Schmitt, D. P., Realo, A., Voracek, M., & Allik, J. (2008). Why can't a man be more like a woman? Sex differences in big five personality traits across 55 cultures. *Journal of Personality and Social Psychology*, *94*(1), 168–182. https://doi.org/10.1037/0022-3514.94.1.168

Smith-Woolley, E., Selzam, S., & Plomin, R. (2019). Polygenic score for educational attainment captures DNA variants shared between personality traits and educational achievement. *Journal of Personality and Social Psychology*, *117*(6), 1145–1163. https://doi.org/10.1037/pspp0000241

Soto, C. J., John, O. P., Gosling, S. D., & Potter, J. (2011). Age differences in personality traits from 10 to 65: Big Five domains and facets in a large cross-sectional sample. *Journal of Personality and Social Psychology*, *100*(2), 330–348. https://doi.org/10.1037/a0021717

Stephan, Y., Demulier, V., & Terracciano, A. (2012). Personality, self-rated health, and subjective age in a life-span sample: The moderating role of chronological age. *Psychology and Aging*, *27*(4), 875–880. https://doi.org/10.1037/a0028301

Stolarski, M., Gorgol, J., & Matthews, G. (2021). The search for causality of personality-chronotype associations: Insights from a one-year longitudinal study of adolescents. *Chronobiology International*, *38*(4), 489–500. https://doi.org/10.1080/07420528.2020.1867157

Susman, E. J., Dockray, S., Schiefelbein, V. L., Herwehe, S., Heaton, J. A., & Dorn, L. D. (2007). Morningness/eveningness, morning-to-afternoon cortisol ratio, and antisocial behavior problems during puberty. *Developmental Psychology*, *43*(4), 811–822. https://doi.org/10.1037/0012-1649.43.4.811

Sutin, A. R. (2015). Openness. In T. A. Widiger (Ed.), *The Oxford handbook of the five factor model* (pp. 83–104). Oxford University Press.

Terracciano, A., Sutin, A. R., McCrae, R. R., Deiana, B., Ferrucci, L., Schlessinger, D., Uda, M., & Costa, P. T. (2009). Facets of personality linked to underweight and overweight. *Psychosomatic Medicine*, *71*(6), 682–689. https://doi.org/10.1097/PSY.0b013e3181a2925b

Tsaousis, I. (2010). Circadian preferences and personality traits: A meta-analysis. *European Journal of Personality*, *24*, 356–373. https://doi.org/10.1002/per.754

Urbán, R., Magyaródi, T., & Rigó, A. (2011). Morningness-eveningness, chronotypes and health-impairing behaviors in adolescents. *Chronobiology International*, *28*(3), 238–247. https://doi.org/10.3109/07420528.2010.549599

Vainik, U., Baker, T. E., Dadar, M., Zeighami, Y., Michaud, A., Zhang, Y. U., García Alanis, J. C., Misic, B., Collins, D. L., & Dagher, A. (2018). Neurobehavioral correlates of obesity are largely heritable. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(37), 9312–9317. https://doi.org/10.1073/pnas.1718206115

Vainik, U., Mõttus, R., Allik, J., Esko, T., & Realo, A. (2015). Are trait-outcome associations caused by scales or particular items? Example analysis of personality facets and BMI. *European Journal of Personality*, *29*, 622–634. https://doi.org/10.1002/per.2009

van den Berg, S. M., de Moor, M. H. M., Verweij, K. J. H., Krueger, R. F., Luciano, M., Arias Vasquez, A., Matteson, L. K., Derringer, J., Esko, T., Amin, N., Gordon, S. D., Hansell, N. K., Hart, A. B., Seppälä, I., Huffman, J. E., Konte, B., Lahti, J., Lee, M., Miller, M., … Boomsma, D. I. (2016). Meta-analysis of genome-wide association studies for extraversion: Findings from the genetics of personality consortium. *Behavior Genetics*, *46*(2), 170–182. https://doi.org/10.1007/s10519-015-9735-5

van der Vinne, V., Zerbini, G., Siersema, A., Pieper, A., Merrow, M., Hut, R. A., Roenneberg, T., & Kantermann, T. (2014). Timing of examinations affects school performance differently in early and late chronotypes. *Journal of Biological Rhythms*, *30*(1), 53–60. https://doi.org/10.1177/0748730414564786

Vazire, S. (2006). Informant reports: A cheap, fast, and easy method for personality assessment. *Journal of Research in Personality*, *40*, 472–481. https://doi.org/10.1016/j.jrp.2005.03.003

Vecchione, M., Alessandri, G., Barbaranelli, C., & Caprara, G. (2012). Gender differences in the Big Five personality development: A longitudinal investigation from late adolescence to emerging adulthood. *Personality and Individual Differences*, *53*(6), 740–746. https://doi.org/10.1016/j.paid.2012.05.033

Vukasović, T., & Bratko, D. (2015). Heritability of personality: A meta-analysis of behavior genetic studies. *Psychological Bulletin*, *141*, 769–785. https://doi.org/10.1037/bul0000017

Walker, R. J., Kribs, Z. D., Christopher, A. N., Shewach, O. R., & Wieth, M. B. (2014). Age, the Big Five, and time-of-day preference: A mediational model. *Personality and Individual Differences*, *56*, 170–174. https://doi.org/10.1016/j.paid.2013.09.003

Weiss, A., & Costa, P. T. Jr (2005). Domain and facet personality predictors of all-cause mortality among Medicare patients aged 65 to 100. *Psychosomatic Medicine*, *67*(5), 724–733. https://doi.org/10.1097/01.psy.0000181272.58103.18

Williams, M. N., Gomez Grajales, C. A., & Kurkiewicz, D. (2013). Assumptions of multiple regression: Correcting two misconceptions. *Practical Assessment, Research, and Evaluation*, *18*(11), 1–14. https://doi.org/10.7275/55hn-wk47

Wittmann, M., Paulus, M., & Roenneberg, T. (2010). Decreased psychological well-being in late "chronotypes" is mediated by smoking and alcohol consumption. *Substance Use & Misuse*, *45*(1–2), 15–30. https://doi.org/10.3109/10826080903498952

Zavada, A., Gordijn, M. C. M., Beersma, D. G. M., Daan, S., & Roenneberg, T. (2005). Comparison of the Munich chronotype questionnaire with the Horne-Östberg's morningness-eveningness score. *Chronobiology International*, *22*(2), 267–278. https://doi.org/10.1081/CBI-200053536

## SUPPORTING INFORMATION

Additional Supporting Information may be found online in the Supporting Information section.

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