Sleep Timing - Variability and Stability, Influences, and Outcomes

by

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Thesis

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Contents

List of Tables

List of Figures

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Declarations

This thesis is submitted to the University of Warwick in support of the application for the degree of Doctor of Philosophy. It has been composed by the author and has not been submitted in any previous application for any degree. Parts of this dissertation have been published or submitted for publication by the author:

Chapter 2: 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 mid-sleep on free and workdays. *Journal of Biological Rhythms.* Advance online publication. doi: 10.1177/0748730420974842

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Chapter 4: Lenneis, A., Das-Friebel, A., Tang, N. K. Y., Singmann, H., Lemola, S., Wolke, D., von Mühlenen, A., & Realo, A. (n.d.). The impact of sleep on next day's subjective well-being: An experience sampling study. *Manuscript under review.*

Abstract

Sleep timing, i.e., chronotype, can be conceptualised as mid-sleep which is the mid-point between sleep onset and wake-up time. This thesis aims to further explore the construct by assessing changes in sleep timing, the *influence* of the five-factor model (FFM) personality traits on sleep timing, and the influence of sleep timing on subjective well-being (*outcome*).

The thesis uses data from an experience sampling study of British university students and a large-scale sample of participants from the Estonian Biobank. Chapter 2 assesses the intraindividual variability of mid-sleep, using a two-week long sleep diary, and temporal stability of mid-sleep on free and workdays of up to five years, by examining their test-retest correlations. Chapter 3 examines the relationship between the FFM personality traits and chronotype on the phenotypic and genetic level using personality and chronotype questionnaires and polygenic scores. Participants of the experience sampling study also provided multiple daily measures of subjective well-being (Chapter 4) allowing the analysis of the influence of sleep timing and other sleep indicators on subjective well-being.

The intraindividual variability of mid-sleep was smaller than the interindividual variability of mid-sleep once the effect of free and workdays was accounted for. The temporal stability of mid-sleep on both free and workdays was strong, but largely dependent on participants' age. The FFM personality traits and chronotype were related at all three levels of the personality hierarchy (i.e., domains, facets, and items) and seemed to share underlying genetic mechanisms. Sleep satisfaction, but not sleep timing, influenced all three components of next day's subjective well-being.

The findings of the thesis offer a wide range of practical implications which could lead to an overall improvement of people's well-being. The thesis closes with directions for future studies that can dive deeper into better understanding sleep timing and its associated factors and outcomes.

Acronyms

DLMO Dim Light Melatonin Onset.

FFM Five-Factor Model (of Personality).

GWAS Genome Wide Association Studies.

LS Life Satisfaction.

MCTQ Munich Chronotype Questionnaire.

MSF Mid-Sleep on Free Days.

MSF_{sc} Mid-Sleep on Free Days Corrected for Sleep Debt.

MSW Mid-Sleep on Workdays.

NA Negative Affect.

NEO-PI-3 NEO Personality Inventory-3.

PA Positive Affect.

PGS Polygenic Score.

SCN Suprachiasmatic Nuclei.

SNP Single Nucleotide Polymorphism.

SWB Subective Well-Being.

Chapter 1

Introduction

Sleep has long been a fascination, from early philosophers, and a focus of scientific inquiry as early as medieval times (Espie & Morin, 2012). Sleep is topic of many research disciplines such as psychology, biology, medicine, and pharmacology. Since the 1950s, research on sleep has grown exponentially and has revealed that it is a “varied, complex, and active arrangement of processes” (Espie & Morin, 2012, p. 2). Thus, there is also an active process that produces sleep (Moorcroft, 2013). Today’s accepted definition of sleep refers to sleep as a “reversible behavioral state of low attention to the environment typically accompanied by a relaxed posture and minimal movement” (Moorcroft, 2013, p. 24). Therefore, the definitions of sleep are very broad. The importance of sleep has been widely recognised; it has even been argued that sleep should be viewed as vital to health as exercise and diet (Perry, Patil, & Presley-Cantrell, 2013) as many dimensions of sleep have been related to health and mortality (Buysse, 2014; Irwin, 2015; Patel & Hu, 2008; Roenneberg, Allebrandt, Merrow, & Vetter, 2012; Steptoe, Peacey, & Wardle, 2006).

The primary focus of the thesis is to better understand one dimension of sleep, i.e. sleep timing and how factors such as time, age and personality are associated with sleep timing. I will also examine how sleep timing and other indicators of sleep are related to subjective well-being. In this chapter, I will first provide a general overview of sleep, especially in terms of when and why we sleep and its relation to the two-process model of sleep regulation. I will particularly focus on sleep timing, i.e., chronotype. At the end of the chapter, I will introduce the empirical studies that comprise the thesis and how they contribute to existing literature.

1.1 How Can Sleep Be Measured?

Sleep can be measured across multiple levels of analysis and along multiple aspects or dimensions (Buysse, 2014). Levels of analysis include self-reports (usually questionnaires), behavioural, physiological, circuit, cellular and genetic levels which can be further divided into multiple dimensions such as quantity (sleep duration), continuity (sleep onset latency, wake after sleep onset) and timing (chronotype; Buysse, 2014; Hall, 2010; Hall, Okun, Atwood, Buysse, & Strollo, 2008). Some dimensions of sleep such as sleep quality can only be measured at one level of analysis (self-reports; Buysse, 2014) as sleep quality judgments seem to be determined by not only what happens during sleep, but also what happens after the sleep period (Ramlee, Sanborn, & Tang, 2017). Therefore, they include an evaluative component that also covers the wake period (Ramlee et al., 2017).

In psychological research, sleep is mostly studied at the physiological, behavioural, and self-report level. The gold standard of sleep assessment remains the physiological polysomnography (Girschik, Fritschi, Heyworth, & Waters, 2012) which records three parameters: brain waves, eye movements, and neck muscle tension (Moorcroft, 2013) which in turn can identify the stages of sleep (sleep structure) and wakefulness. However, both subjective (e.g., self-reported questionnaires, sleep diaries) and objective/behavioural measures (e.g., actigraphy[1]) of sleep are good alternative assessments to polysomnography as they are more practical and cost-effective.

In my thesis, I will examine sleep on multiple levels of analysis (self-report, behavioural, i.e., actigraphy-derived, and genetic levels) and multiple dimensions (sleep quantity, continuity, timing, and quality/satisfaction). I chose these specific dimensions as they have been related to subjective well-being (see Section 1.6, Chapter 4). However, the main focus of my thesis will be on sleep timing, i.e., chronotype, which I will examine by using self-reported questionnaires, actigraphy, and DNA samples.

1.2 When and How Long Do We Sleep?

The current understanding about how sleep and wakefulness are regulated is heavily influenced by the two-process model of sleep regulation which explains how two independent processes play a role in when people sleep and are awake (Borbély, 1982). In short, it assumes that both sleep duration and sleep structure (i.e., rapid eye movement sleep, non rapid-eye movement sleep, slow wave activity) are driven by sleep homeostasis, allowing for recovery of lost sleep as well as being influenced by circadian clocks (Dijk & Lazar, 2012).

The two processes the model postulates are a sleep-dependent process (Process S) and a sleep-independent circadian process (Process C) which interact continuously with each other (Borbély, Daan, Wirz-Justice, & Deboer, 2016). Process S itself is determined by sleep and waking and represents sleep debt. It increases during wakefulness and decreases during sleep (Borbély et al., 2016). Process C is a process controlled by a circadian pacemaker of approximately 24 hours which imposes

[1]Actigraphs are wrist-worn devices that record movements that can be used to estimate sleep parameters (Martin & Hakim, 2011).

rhythmicity on the brain and the body (Dijk & Lazar, 2012). Sleep propensity (i.e., the time it takes to fall asleep) and the duration of sleep is assumed to be determined by the combined actions of the two processes. Even if participants experience detrimental amounts of sleep deprivation (Process S), they still do not recover as much sleep as they have lost (Rosenthal, Merlotti, Roehrs, & Roth, 1991). The sleeping brain tries to compensate the sleep deprivation by increasing sleep depth (Borbély, Baumann, Brandeis, Strauch, & Lehmann, 1981). Thus, sleep deprivation results in a longer sleep duration, but not all lost sleep can be recovered immediately (Dijk & Lazar, 2012), highlighting the combined actions of Process S and Process C in the length and timing of sleep. The two processes are also sometimes opposing each other. Sleep pressure in the early evening is very high whereas the circadian drive is very low, which is also referred as sleep maintenance zone (de Zeeuw et al., 2018). During this time, subjective and objective alertness is high. Undisturbed sleep (high sleep efficiency) of eight hours can only be maintained when sleep onset is close to end of the wake maintenance zone so that the circadian drive for sleep has already risen (Czeisler & Dijk, 1994). Thus, a precise alignment the two processes is necessary in order to ensure a good night's sleep.

1.3 The Independence of the Circadian Process (Process C)

Under natural circumstances, endogenous circadian rhythms are synchronised with/entrained to light and dark of the 24-hour day, meaning that behavioural and physiological events (e.g., changes in temperature, sleep phases, hormone secretion, enzyme synthesis, etc.) typically occur at a certain time (Schulz & Steiner, 2009). There are several *zeitgebers* (time-givers), i.e., periodic inputs from the environment that contain information on time, that the circadian clock entrains to, and light is the most important one (Aschoff, 1965). The *zeitgebers* set the timing of the clock (Karthikeyan et al., 2014), but they are not the clock themselves.

In mammals, circadian rhythms are mainly regulated by paired suprachiasmatic nuclei (SCN) of the hypothalamus which are clustered against the third ventricle and sit above the optic chiasm (Hastings, Maywood, & Brancaccio, 2018). The SCN are essential for orchestrating circadian behaviour (Hastings et al., 2018) such as body temperature, locomotor activity, drinking, gnawing, and hormone secretion (Silver & Rainbow, 2013). Both in vivo and ex vivo, cells exhibit a pronounced circadian cycle of electrical firing, reaching their peak at daytime (Hastings, Maywood, & Brancaccio, 2019). The SCN obtain information about light through melanopsin-containing photoreceptors in the retina which do not form images. Contrary to previous beliefs that assumed that Process C was only under strict control of the SCN (Borbély et al., 2016), circadian clocks are not only located in the SCN but also situated in most tissues and organs (Balsalobre, Damiola, & Schibler, 1998; Yagita, Tamanini, van der Horst, & Okamura, 2001). The supervision of this mechanism at a molecular level is built upon the interactions of several genes known as circadian or "clock" genes (Ferrer et al., 2020). Clock genes are defined as "genes whose protein products are necessary components for the generation and regulation of circadian rhythms" (Lowrey & Takahashi, 2004, p. 412). Clock genes participate in interconnected positive and negative autoregulatory feedback loops (reviewed by Lowrey & Takahashi, 2004). Some of the most well-known clock genes are: CLOCK, PER1, PER2, and CRY1 (see for example Lowrey & Takahashi, 2004).

Several studies have shown that circadian rhythms differ from exactly 24 hours when no *zeitgebers* are present which is called a *free running period* (Schulz & Steiner, 2009). One of the first experiments on circadian rhythms was conducted in 1938 by Nathaniel Kleitman and Bruce Richardson who spent a month in chamber in Mammoth Cave, Kentucky, where they encountered maximal darkness and a constant temperature of 12° Celsius. They found some regularities in the circadian rhythm of body temperature and concluded that circadian rhythms were not influenced by some cosmic forces but rather by activity of the organism such as rest, movement, food intake, and sleep (Kleitman, 1963). In the 1960s, Aschoff (1965) conducted a study where participants (including Aschoff himself) lived in a bunker without any natural *zeitgebers* for three to four weeks. He found that on average, participants had a free running period of 25 hours, but the prolonged period of more than 24 hours might be because of participants being allowed to turn on and switch off the lights when they wanted which also influences circadian rhythms. In a study that used a protocol of forced desynchrony, Czeisler et al. (1999) found that the misalignment between humans and environment was much smaller than previously reported as the human circadian pacemaker averaged 24.18 hours. Thus, when humans live in an environment where they do not entrain to the 24-hour clock, their circadian pacemaker is slightly longer than 24 hours.

1.4 Peripheral Rhythms as Markers for Circadian Phase

There are a wide range of physiological and behavioural variables in humans that follow a circadian rhythm (Czeisler & Dijk, 2001). Peripheral rhythms like core body temperature, cortisol, and melatonin rhythms have been used widely as markers for circadian phase of the SCN (Dijk & Duffy, 2020). Studies have shown that these biomarkers are sleep independent, meaning that they also follow a circadian rhythm in the absence of sleep (see for example Czeisler et al., 1990).

Human body temperature was one of the first markers that was identified to follow a circadian rhythm and it has been shown that it reaches its peak in the early evening hours and its lowest point in second half of the night (Czeisler & Dijk, 2001). Sleeping at night also occurs at a particular endocrine environment (Dijk & Lazar, 2012). Readiness for sleep is started off by the release of the hormone melatonin by the pineal gland. It induces distal vasodilation, thus heat loss which increases probability of sleep onset (Kräuchi & Wirz-Justice, 2001). Melatonin levels typically are the highest during the night and lowest in the morning (Lynch, Wurtman, Moskowitz, Archer, & Ho, 1975). The gold standard for a circadian phase marker is dim light melatonin onset (DLMO; Kantermann & Eastman, 2018) which is the time point when melatonin levels begin to rise in the evening (Lewy, Cutler, & Sack, 1999). The adrenal hormone, cortisol, follows a different pattern. Cortisol typically increases throughout the night and reaches its peak when getting up (Copinschi & Challet, 2016).

Studying endocrine markers in general as well as body temperature is very time consuming, costly, and sometimes intrusive. These markers are often only studied in the laboratory under constant conditions (Kantermann & Burgess, 2017; Kantermann & Eastman, 2018; Roenneberg, Pilz, Zerbini, & Winnebeck, 2019) or in the field using a certain protocol (Baehr, Revelle, & Eastman, 2000). Laboratory and field studies have shown that the timing of peripheral rhythms can be different across humans (Baehr et al., 2000; Burgess & Fogg, 2008; Linkowski et al., 1993; Selmaoui & Touitou, 2003), indicating that these individual differences might also influence the timing of people's sleep.

1.5 Morningness-Eveningness and Chronotype

Variation in sleep timing among humans is considerable, even to the extremes that some of us go to sleep when others wake up (Dijk & Lazar, 2012). This phenomenon is often referred to as morningness-eveningness (Horne & Östberg, 1976) or chronotype (Roenneberg, Wirz-Justice, & Merrow, 2003). Morningness-eveningness refers to individuals' preferences of what time they go to bed and wake up (Dijk & Lazar, 2012) whereas chronotype refers to a time of day, when an individual's endogenous clock synchronizes (entrains) to the 24-hour day (Roenneberg et al., 2004). Morningness-eveningness and chronotype are seen as distinct constructs (Roenneberg, 2015), yet are highly correlated with each other (Zavada, Gordijn, Beersma, Daan, & Roenneberg, 2005). Both morningness-eveningness and chronotype have been shown to be normally distributed (Caci, Nadalet, Staccini, Myquel, & Boyer, 2000; Kantermann, Sung, & Burgess, 2015; Roenneberg et al., 2003), so that only a few people are extremely morning/evening people or very early/late chronotypes. An early chronotype is someone who falls asleep and wakes up early whereas someone with a late chronotype falls asleep and wakes up much later. In the studies that comprise my thesis (Chapters 2-4), I will only examine chronotype. However, as previous research has often focused on morningness-eveningness, I will also review studies that have assessed morningness-eveningness.

Chronotype can be operationalised as midpoint of sleep which has been shown to correlate strongly (r = .66) with DLMO (Terman, Terman, Lo, & Cooper, 2001), thus indicating that Process C largely influences chronotype. However, bedtimes are also influenced by Process S as they depend on previous days' sleep durations (Borbély, 1982; Borbély et al., 2016). In an attempt to reduce the influence of sleep pressure (Process S), Roenneberg et al. (2003) assess chronotype as the midpoint of sleep on free days which can further be corrected for accumulated sleep debt when no alarm clock is used on the free days. Furthermore, sleep times under natural conditions are also influenced by other circumstances which are partly self-selected by the individuals themselves (Czeisler & Buxton, 2017). Thus, Roenneberg et al. (2019) proposed to add a third, so-called social component to the two-process model of sleep regulation to explain sleep timings under natural conditions. The social component includes societal (e.g., the weekly structure, holidays, daylight saving time) and work or family schedules (e.g., child care, school and work responsibilities), but also human behaviour such as watching late TV shows, interacting with friends, attending entertaining events, staying up late to read a thrilling book, or being active on social media (Roenneberg et al., 2019). These behaviours might prevent people from going to bed when they should/could (Roenneberg et al., 2019).

When Process C and the social component are not aligned with each other, it can result in social jetlag which is a chronic form of jetlag (i.e., a misalignment between the circadian and solar clocks; Wittmann, Dinich, Merrow, & Roenneberg, 2006; Wittmann et al., 2006) or a small but chronic version of shift work (Roenneberg et al., 2012). It is operationalised as the absolute difference between mid-sleep on free and workdays (Wittmann et al., 2006) and is confounded by sleep debt (Roenneberg et al., 2019) which it can also be corrected for (Jankowski, 2017). Social jetlag is most pronounced in late chronotypes since they often have to get up early in the morning for work which leads to an increasing sleep debt over the week which they compensate for on weekends but it also exists in early chronotypes when they go to bed late and wake up naturally early on the following day (Wittmann et al., 2006).

The social component of the model, in particular human behaviour, could also be influenced by personality. Behaviour is an implicit component of personality (Asendorpf & Rauthmann, 2020; Johnson, 1997). Environmental factors such as noise, artificial light, and the use of alarm clocks enable individuals to override the signals they get from Process C and Process S, so that they can decide themselves what time they would like to go to bed and wake up in order to fulfil their work or school requirements, or to attend recreational and social events (Czeisler & Buxton, 2017). Thus, people with different personalities might alter their environments and choose different bed and wake-up times.

Another factor that is strongly related with chronotype is age (Adan et al., 2012). However, the relationship between age and chronotype is complex. Age seems to be an overarching variable that influences chronotype through multiple pathways. In the next section, I will further elaborate on this. I will also examine in more detail the genetic component of chronotype and the relationship between personality and chronotype as they are topics of my thesis.

1.5.1 Stability of Chronotype

Cross-sectional studies have shown that humans experience a shift in chronotype/ morningness-eveningness during the course of the lifespan. Toddlers are typically early chronotypes (Simpkin et al., 2014) and chronotype steadily increases until the end of adolescence which is also when it reaches its peak (Roenneberg et al., 2004). Roenneberg et al. (2004) therefore also refer to chronotype as a marker for the end of adolescence. After the end of adolescence, people become more morning oriented with increasing age, even when controlling for demographic and socioeconomic factors (see Adan et al., 2012, for a review). However, within a certain age group, chronotype is normally distributed but the respective means by age vary systematically, so that the means increase until the end of adolescence and then steadily decrease until older age (Roenneberg et al., 2007). People seem to maintain their position relative to others, i.e., rank-order stability (reviewed by B. J. Taylor & Hasler, 2018), even if chronotype scores decrease with time. Roenneberg et al. (2019) recently suggested that chronotype should be seen as a state and not a trait since under natural conditions *zeitgeber* signals vary in strength and timing. Thus, in the laboratory chronotype might be a trait but under natural conditions a state indicating that Process C might remain relatively stable over time, but external influences might also affect the stability of chronotype. During the lockdowns due to COVID-19 in 2020, it was possible to study the influence of external factors as many people did no longer have to commute to work and thus gained some time of their days. However, mixed results have been reported. On the one hand, Staller and Randler (2020) reported that participants experienced less social jetlag when they were working from home but that their chronotype did not change. On the other hand, an Argentinian study found that people's chronotype was significantly delayed during lockdown (Leone, Sigman, & Golombek, 2020). It also remains unclear how modifiable chronotype is (B. J. Taylor & Hasler, 2018). The question therefore remains how chronotype varies both over shorter and longer periods of time and how age influences the temporal stability of chronotype (Chapter 2).

Duffy, Dijk, Klerman, and Czeisler (1998) reported that body temperature in healthy older participants was higher than in younger participants during the night. They also showed that older participants on average woke up earlier and had an earlier endogenous circadian phase than younger participants. However, the earlier endogenous circadian phase in older participants was later than their actual wake-up time, indicating that older participants may be more sensitive to light. Duffy et al. (1998) suggested that this might be due a lower sleep pressure which might be explained by evening naps (Yoon et al., 2003). Research has shown that the transition into retirement is associated with longer sleep duration, later bedtimes, and later wake times and thus sleep schedules seem to be constraint by work schedules (Hagen, Barnet, Hale, & Peppard, 2016). Sleep pressure might be weakened due to fewer external influences on sleep timings. In younger participants such as university students, sleep schedules might be more flexible than in middle-aged participants who have stable work schedules and have a family. Therefore, changes in the social component during the lifespan seem to influence Process S and thus the stability of chronotype.

1.5.2 Genetic Contribution of Chronotype

Twin studies and genome-wide association studies (GWAS) have used phenotypic morningness-eveningness as outcome variable. There are no studies that have investigated the genetics of chronotype, and therefore, to inform my research, I am reviewing studies that have used morningness-eveningness. Due to the high correlation between morningness-eveningness and chronotype (Zavada et al., 2005), I assume that the results of these studies would also be true for chronotype. Twin studies have shown that around 50% of the variance in morningness-eveningness can be attributed to genetics (e.g., Barclay, Eley, Buysse, Archer, & Gregory, 2010; Hur, 2007; Koskenvuo, Hublin, Partinen, Heikkila, & Kaprio, 2007).

The genetic contribution of morningness-eveningness can be further explored with GWAS. GWAS 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, Selzam, & Plomin, 2019). Four GWAS have used genome data from two big cohort studies: 23andMe (Hu et al., 2016) and the UK Biobank (Jones et al., 2016; Lane et al., 2016). More recently, Jones et al. (2019) conducted a meta-analysis of the two cohorts with an overall number of 697,828 participants. All studies together have identified a total of 351 SNP loci related with morningness-eveningness including variants within clock genes such as CRY1, PER2, and PER3, along with other genes (reviewed by Maukonen et al., 2020). The meta-analysis increased the number of genetic loci associated with being a morning person from 24 to 351 (Jones et al., 2019).

GWAS have shown that the effect sizes of SNPs in predicting complex traits are usually very small, with each SNP explaining less than 0.1% of the variance (Gratten, Wray, Keller, & Visscher, 2014). Since it is assumed that genetic effects are additive, more variance can be explained when considering the effects of SNPs jointly. It is possible to generate a genetic score for individuals in independent samples by summing up the weighted SNPs (Smith-Woolley et al., 2019). This score is also known as polygenic score (PGS) and allows DNA-based prediction of a certain phenotype (Smith-Woolley et al., 2019). PGSs have already been calculated for morningness-eveningness in several studies (Ferrer et al., 2020; Maukonen et al., 2020; Pesonen et al., 2020). Maukonen et al. (2020) predicted morningness-eveningness from the morningness-eveningness PGS and found that the PGS significantly predicted phenotypic morningness-eveningness at $p < .001$ and accounted for 1.4% of the variation in morningness-eveningness.

Therefore, the PGS of morningness-eveningness shows predictive validity and is also related with variants within clock genes. As chronotype is not only influenced by clock genes (Roenneberg et al., 2019), but also other factors such as human behaviour (Roenneberg et al., 2019), it will be interesting to see whether the PGS for morningness-eveningness also shares genetic mechanisms with other related constructs such as personality. This would indicate a polygenic overlap between the two constructs (Cheesman, Rayner, & Eley, 2019; Turkheimer, Pettersson, & Horn, 2014) which I will explore in Chapter 3.

1.5.3 Personality and Chronotype

Personality psychology tries to describe, predict, and explain recurrent behaviours, thoughts, or feelings that set apart an individual from some or others (Asendorpf & Rauthmann, 2020; Johnson, 1997). Personality is often hierarchically organised by the five-factor model (FFM) of general personality structure which is widely used within Psychology (McCrae & John, 1992; Widiger, 2015) with the highest level of the hierarchy being domains, followed by facets and items ("nuances"; Costa & McCrae, 1992). The FFM has been replicated in many different languages and cultures (Allik & Realo, 2017, 2018) and the same five-factor structure also has been found among self-and observer-ratings (Allik, Realo, & McCrae, 2013).

Several studies have shown that personality traits are related with morningness-eveningness. No studies have been conducted about the relationship between personality and chronotype. A meta-analysis found that morningness was related the strongest with Conscientiousness (Lipnevich et al., 2017), which is one of the FFM personality domains that manifests the disposition to be self-controlled, responsible to others, hardworking, orderly, and rule abiding (Jackson & Roberts, 2015). As human behaviour has an influence on chronotype (Roenneberg et al., 2019), it could be that personality plays an important role of when to go to bed and wake up. On the one hand, personality traits may influence chronotype through shaping people's preferences for various social activities and behaviours. On the other hand, personality may influence chronotype by active decisions people take regarding their bedtimes. Both pathways are described in more detail in Chapter 3, Section 3.4.2.

Personality and chronotype might also be related at a genetic level. Similar to chronotype, around 40-60% of the variance in FFM personality traits can be attributed to heritability based on behavioural genetics studies (Bouchard, 2004). GWAS have identified several loci related to personality (Lo et al., 2017; Montag, Ebstein, Jawinski, & Markett, 2020) which allow the calculation of PGSs. Both personality and chronotype have been linked to similar outcomes such as health and mortality (H. S. Friedman & Kern, 2014; Partonen, 2015). Therefore, it could be that chronotype and personality share a mutual genetic basis.

In Chapter 3, I will examine both the phenotypic and genetic relationship between personality and chronotype.

1.6 The Effect of Sleep on Mood, Emotions, and Subjective Well-Being

Even though people spend so much time of their lives sleeping, it is still not entirely clear why people actually sleep (Harrison, 2012). Sleep seems to be important factor in for example boosting the immune system, reducing caloric intake, restoring brain energy stores, and waking-induced performance degradation. Among other important functions, sleep also plays an integral part in emotion regulation (Hall, Levenson, & Hasler, 2012). In Chapter 4, I will study affect which is influenced by emotion regulation. In the following, I will explain how emotional regulation, emotions, mood, and affect are related with each other.

Emotion regulation refers to different sets of processes by which emotions themselves are regulated such as situation selection, situation modification, attentional deployment (e.g., distraction), cognitive change (e.g., changing a situation's meaning), and response modulation (e.g., going for a run after having experienced an unpleasant emotion; Gross, 2008). The goal of emotion regulation often is to turn down experiential and/or behavioural aspects of negative emotions such as anger, fear, and sadness (Gross, Richards, & John, 2006). However, sometimes people also regulate their positive emotions when they do not want to attract too much attention when, for example, winning a game (Gross, 2008). Thus, emotion regulation influences the emotions that people experience. Emotions are biologically-based reactions to events that help to meet challenges and opportunities, and involve changes in subjective experience, behaviour, and physiology (reviewed by Gruber & Cassoff, 2014). The expression of certain, but not all, emotions is universal (Matsumoto & Hwang, 2019). Emotions and mood are closely related with each other as they often elicit the same feelings for an individual, yet they are distinct constructs (Beedie, Terry, & Lane, 2005). Mood refers to a temporary predisposition to an emotion or to an emotional state of low intensity that can persist long after an emotion-eliciting event has occurred (Oatley & Johnson-laird, 1987). The collective term for emotions and moods is affect (Niven, 2013). Affect helps to regulate behaviour—mood states lead to broad tendencies of approach and avoidance behaviour while emotions are associated with specific action tendencies (Niven, 2013). Affect can be divided into two independent dimensions: positive and negative affect (Watson, Clark, & Tellegen, 1988). Positive and negative affect together with life satisfaction—a measure of global positive affect (Magai, 2008)— compose subjective well-being (Diener, 1984).

Gruber and Cassoff (2014) proposed a framework that identifies the key aspects of sleep and emotion regulation. They posit that both Process S and Process C are influencing emotion regulation. On the one hand, areas in the brain that are responsible for emotion regulation and executive functions are sensitive to sleep deprivation (Gruber & Cassoff, 2014). Thus, emotion regulation might be impaired when sleep pressure is high. On the other hand, mood seems to also be partly regulated by a circadian process. In healthy subjects, mood follows a circadian rhythm, so that it is the lowest in the morning and increases throughout the day, but decreases with extended wakefulness (Boivin et al., 1997; Wirz-Justice, 2008). This has been shown to be true for positive affect (Murray et al., 2009). Variations in mood could affect how a person responds to a certain situation and how well they are able to regulate such a situation (Gruber & Cassoff, 2014). As affect is the umbrella term for emotions and mood (Niven, 2013), it seems to be influenced by both Process S and Process C.

The majority of the literature investigating circadian processes and affective outcomes have focused on chronotypes (Gruber & Cassoff, 2014). On a clinical level, eveningness has been related to an increased risk for mood disorders (Merikanto et al., 2013; Murray, Allen, & Trinder, 2003; Wood et al., 2009) with the PGS of morningness-eveningness also been linked to mood disorders (Ferguson, 2019). Worse psychological well-being in later chronotypes might be explained by social jetlag (Wittmann et al., 2006) although only later chronotypes who smoke and drink suffer from more psychological distress (Wittmann, Paulus, & Roenneberg, 2010). Other dimensions of sleep such as sleep quality, sleep efficiency, and sleep duration have also been independently linked to subjective well-being (see Chapter 4 for a review). In Chapter 4, I am going to relate different dimensions of sleep with next day's subjective well-being.

1.7 Scope and Research Questions

This dissertation explores the variability and stability of sleep timing, how the FFM personality traits are related to sleep timing, and how sleep timing and other dimensions of sleep are related to subjective well-being. Above, I have shown that sleep timing changes with age and that morningness-eveningness is influenced by personality. I have also reviewed that sleep influences components of subjective well-being. Thus, the general aim of my research is to even better understand sleep timing and its associated factors and outcomes.

Each chapter of my thesis will contribute to answering the following research questions:

- RQ1: What is the ratio of the daily intra- and interindividual variability of midpoint of sleep over a period of two weeks when taking into account the effect of free and workdays? (Chapter 2)
- RQ2: How does average daily assessment of midpoint of sleep relate to retrospective and actigraphy-derived assessments? (Chapter 2)
- RQ3: How stable is midpoint of sleep on free and workdays over a period of 0-1 to 5 years when also taking into account the effect of age? (Chapter 2)
- RQ4: How are all three levels of the FFM personality hierarchy related with chronotype both at the phenotypic and genetic level? (Chapter 3)
- RQ5: How are sleep timing as well as other sleep parameters such as sleep onset latency, sleep duration, sleep satisfaction, and sleep efficiency related to next day's subjective well-being within participants? (Chapter 4)

1.8 Outline of the Dissertation

The chapters of the dissertation are outlined below.

1.8.1 Chapter 2: Intraindividual Variability and Temporal Stability of Mid-Sleep on Free and Workdays

Chapter 2 aims to answer RQ1, RQ2, and RQ3 by using data from two studies: a two-week experience sampling study of British university students and a panel study of Estonian adults from the Estonian Biobank. The Estonian Biobank is a large scale sample of the Estonian population which roughly reflects age, gender, and education of the general population (Leitsalu et al., 2014).

I will first examine the variability of midpoint of sleep over a 14-day-period in University students while also taking into account the effect of free and workdays on mid-sleep. I also will validate the average self-reported daily assessments of midpoint of sleep with retrospectively assessed self-reports (MCTQ) and actigraphy-derived measures.

In the second study, I explore the temporal stability of mid-sleep of both free and workdays when participants filled in the Munich Chronotype Questionnaire (MCTQ; Roenneberg et al., 2003) 0-1 to 5 years apart from each other. I also investigate how the temporal stability of mid-sleep is dependent on age and discuss how life circumstances might affect the stability of mid-sleep.

1.8.2 Chapter 3: The Five-Factor Model of Personality Domains, Facets, and Nuances Is Associated With Chronotype at Both the Phenotypic and Genetic Level

In Chapter 3, I will examine RQ4 by again using data from the Estonian Biobank. Participants filled in the Estonian version of the NEO-PI-3 (McCrae, Costa, & Martin, 2005) personality inventory which allows to examine personality at all three levels of the FFM personality hierarchy. They also completed the MCTQ (Roenneberg et al., 2003) that I used to assess mid-sleep corrected for sleep debt (chronotype). Participants also donated their DNA which allowed the calculation of PGSs for personality and chronotype.

I relate chronotype with personality on all three levels of the personality hierarchy, that is, domains, facets, and items. I also discuss possible pathways of how personality might influence one's behaviours when making the decision of when to go to bed. To shed light on how personality and chronotype are related on a genetic level, I analyse the genetic contribution of personality and chronotype and phenotypic chronotype and personality using PGSs.

1.8.3 Chapter 4: The Impact of Sleep on Subjective Well-Being

Chapter 4 explores the wider functions of sleep. It uses the experience sampling data from British university students and will examine RQ5. I examine how daily fluctuations from one's average sleep indicators (sleep onset latency, sleep duration, sleep timing/social jetlag, sleep satisfaction, and sleep efficiency) impact next day's three components of subjective well-being (i.e., positive affect, negative affect, and life satisfaction) in a natural setting. I will measure the three variables independently from each other as they have been linked to different outcome variables (Realo, Johannson, & Schmidt, 2017).

1.8.4 Chapter 5: General Discussion

Following up on the presented research, Chapter 5 offers a general discussion and conclusion of the findings as well as ideas for future research.

Chapter 2

Intraindividual Variability and Temporal Stability of Mid-Sleep on Free and Workdays

Abstract: As I have highlighted in Chapter 1, people differ in their sleep timing which is often referred to as a chronotype. Chronotype can be operationalised as mid-sleep, i.e., midpoint between sleep onset and wake-up. I also reviewed that cross-sectional studies have shown that chronotype changes with age. The aims of the present studies were to examine intraindividual variability and longer-term temporal stability of mid-sleep on free and workdays, while also considering the effect of age. We used data from a two-week experience sampling study of British university students (Study 1) and from a panel study of Estonian adults who filled in the Munich Chronotype Questionnaire twice up to five years apart (Study 2). Results of Study 1 showed that roughly 50% of the variance in daily mid-sleep scores across the 14-day period was attributed to intraindividual variability as indicated by the intraclass correlation coefficient. However, when the effect of free versus workdays was considered, the intraindividual variability in daily mid-sleep across two weeks was 0.71 the size of the interindividual variability. In Study 2, mid-sleep on free and workdays showed good levels of temporal stability—the retest correlations of mid-sleep on free and workdays were .66 and .58 when measured twice over a period of 0-1 to 5 years. The retest stability of mid-sleep scores on both free and workdays sharply increased from young adulthood and reached their peak when participants were in late 40-early 50 years of age, indicating that age influences the stability of mid-sleep. Future long-term longitudinal studies are necessary to explore how age-related life circumstances and other possible factors may influence the intraindividual variability and temporal stability of mid-sleep.

2.1 Introduction

Timing of sleep is an indicator of chronotype (Roenneberg et al., 2003) and is not identical with morningness-eveningness which refers to one's preference or natural inclination to go to and get out of bed (Horne & Östberg, 1976). The two are strongly related, yet distinct, constructs (Zavada et al., 2005). Chronotype, on the one hand, refers to a time of day, namely when an individual's endogenous clock synchronizes (entrains) to the 24-hour day (Roenneberg et al., 2004) and is often operationalised as mid-sleep, i.e., midpoint between sleep onset and wake-up (Terman et al., 2001). Morningness-eveningness, on the other hand, is a diurnal preference for what time to go to and get out of bed, including at what time during the day an individual is most alert and can perform best (Horne & Östberg, 1976). People with an early or morning chronotype tend to wake up and to go to bed relatively early whereas those with a late or evening chronotype tend to sleep longer in the morning and to go to bed later. Chronotype has a strong biological and genetic basis with roughly half of the variance being attributed to heritability (see e.g., Barclay et al., 2010; Hur, 2007; Koskenvuo et al., 2007), whereas the remaining variance can be accredited to environmental and social factors such as the exposure to natural sunlight (Roenneberg et al., 2007), artificial light (Vetter, Juda, Lang, Wojtysiak, & Roenneberg, 2011), social and professional demands (Abbott, Reid, & Zee, 2017; Leonhard & Randler, 2009), and personality (Lipnevich et al., 2017, Chapter 3).

2.1.1 Intraindividual Variability and Temporal Stability of Chronotype and Morningness-Eveningness

Despite sleep being an area of fast-developing interest due to its important role in people's physical and mental health (e.g,. Espie & Morin, 2012), the temporal stability of chronotype and morningness-eveningness across time has received far less attention. What is known from cross-sectional studies is that chronotype and morningness-eveningness vary with age: People are typically morning-oriented in childhood, become later chronotypes during adolescence with chronotype and morningness-eveningness peaking in lateness around the age of 18-20 years, and then gradually become earlier chronotypes again with increasing age, even more so from the age of 50 years (see Adan et al., 2012, for a review). However, cross-sectional studies do not allow us to examine intraindividual variability or change over time as any findings in cross-sectional studies may be due to cohort or period effects rather than age-related changes per se (Jacob & Ganguli, 2016; Realo & Dobewall, 2011). A study by Broms and colleagues 2014, for instance, examined morningness-eveningness across generations in the 1980s and 2000s and showed that there were less morning people and more evening people in the 2000s compared to the 1980s, indicating that the distribution of morningness-eveningness may be different across generations.

Most of the studies that have looked into the temporal stability of chronotype and morningness-eveningness have done so over relatively short periods of time in the course of validating and establishing test-retest reliabilities of chronotype and morningness-eveningness questionnaires[1]. Table 2.1 gives an overview of the previously conducted studies investigating test-retest correlations in sleep-time-based assessments of chronotype and preferential morningness-eveningness questionnaires over both shorter and longer periods of time. Generally speaking, the test-retest reliabilities of both types of questionnaires have been found to be quite high (i.e., range between r = .76 and .97) when the same participants were tested one to four months apart from each other. However, the test-retest reliabilities seem to decrease with longer time intervals. A longitudinal study by Urner, Tornic, and Bloch (2009), for instance, used actigraphy-based measures of mid-sleep on free days (chronotype) and workdays in a sample of 17-19 year-old students and found that the mid-sleep scores on free and workdays were correlated at r = .55 and .58 (p <.05) across two measurements five years apart, respectively. Also, when measuring the stability of diurnal type in a small subsample of the Older Finnish Twin Cohort, the findings of Koskenvuo and colleagues 2007 showed that there was a significant shift towards being a more morning person with increasing age across a six-year period.

[1]One should choose what kind of questionnaire to use according to one's research aims and questions (Roenneberg, 2015).

Table 2.1

Review of Studies Investigating Test-Retest Reliabilities of Preferential Morningess-Eveningness and Sleep Time Based Assessments of Chronotype

Study	**Measurement**	***N***	**Time duration**	***r***	***p***	**Age span in years**	**Mean age in years (*SD*)**
Preferential Questionnaires							
Pündük et al. (2005)	MEQ	618	15-20 days	.84	<.001	18 to 57	23.00 (5.40)
Lee et al. (2014)	MEQ	21	4 weeks	.90	<.001	20-39*	N/A
Griefahn et al. (2001)	MEQ	43	7 to 12 weeks	.97	<.001	18-68*	23.4 (7.1)*
Neubauer (1992)	MEQ	48	2 months	.89	N/A	18-47*	N/A
Greenwood (1994)	CSM	36	3 months	.91	<.001	18-52*	21.3*
Larsen (1985)	MEQ	74	3 months	.88	N/A	N/A (University students)	N/A
Greenwood (1994)	CSM	35	9 months	.82	<.001	18-52*	21.3*
Caci et al. (2000))	CSM	60 (49 females, 11 males)	13 months	.93 (females), .86 (males)	<.001	18-40	22.51 (4.37)
Kantermann and Eastman (2018)	MEQ	18	9 months to 3 years	.85	<.001	21-44	N/A

Continued on next page

Table 2.1 continued from previous page

Study	**Measurement**	***N***	**Time duration**	***r***	***p***	**Age span in years**	**Mean age in years (*SD*)**
Wood et al. (2009)	CSM	52	2 years	.72	<.001	N/A (adults, offspring between 2 and 18 years)	N/A
Reports of Sleep Times							
Reis et al. (2020)	MCTQ	41	2-6 weeks	rho = .83 (MSW), rho = .83 (MSF), rho = .91 (MSF_{sc})		18-64	44.12 (14.54)
Kühnle (2006)	MCTQ	15	up to 3 weeks	.81	< .001	N/A	N/A
Suh et al. (2018)	MCTQ	78 (only females)	3 months	.73 (MSW), .72 (MSF), .72 (MSF_{sc})	< .001	20-27	21.83 (1.67)
Kühnle (2006)	MCTQ	96	Aug-Sept to January (5-6 months)	.88	< .001	N/A	N/A

Continued on next page

Table 2.1 continued from previous page

Study	**Measurement**	***N***	**Time duration**	***r***	***p***	**Age span in years**	**Mean age in years (*SD*)**
McMahon et al. (2018)	MCTQ	390	6, 12, 18, and 24 months	test-retest correlations not reported; MSF_{sc} declined over time; shift to earlier chronotype only observed in late chronotype group		21-35	27.6 (3.8)
Kantermann and Eastman (2018)	MCTQ	18	9 months to 3 years	.78	< .001	21-44	N/A
Urner et al. (2009)	Actigraphic MSW and MSF	23	5 years	.58 (MSW), .55 (MSF)	<.05	17-19 at T1	18.4 (0.9) at T1; 23.4 (0.9) at T2
Druiven et al. (2020)	MCTQ	1,417	7 years	.53	<.001	18-65	N/A

Note. MEQ = Morningness-Eveningness Questionnaire (Horne & Östberg, 1976); CSM = Composite Scale of Morningness (Smith, Reilly, & Midkiff, 1989); MCTQ = Munich Chronotype Questionnaire Munich Chronotype (Roenneberg et al., 2003) r = test-retest correlation; N = sample size; MSW = mid-sleep on workdays; MSF = mid-sleep on free days; MSF_{sc} = mid-sleep on free days corrected for sleep debt; * = only a subsample filled out the questionnaires twice, N/A = not available; only the age of the whole sample was reported; T1 = first time of assessment; T2 = second time of assessment.

The intraindividual or within-person variability in chronotype, that is how an individual's chronotype or mid-sleep fluctuates from one day to another (Mroczek & Spiro, 2003), has rarely been examined. Such studies need intensive repeated measurement designs and hence are harder to conduct. A fourteen-day experience sampling study, for instance, that investigated night-to-night variability in various sleep behaviours and measures found that both participants with and without chronic insomnia had substantial night-to-night variations in quantitative and qualitative sleep diary measures as well as in actigraphy-based measures of sleep (Buysse et al., 2009). A related study found that adolescents with ADHD had greater intraindividual variability in their bed- and wakeup times than adolescents without ADHD (Langberg et al., 2019). These studies suggest that there might also be daily fluctuations in mid-sleep time points. When investigating biological markers of circadian rhythms during three 24-hour sessions in the laboratory, Selmaoui and Touitou (2003) reported that participants had very little daily intraindividual variability of cortisol circadian rhythm parameters and fairly little daily intraindividual variability in melatonin parameters. Differently from humans, however, there are quite some studies that have investigated the inter-and intraindividual variability of circadian rhythms in animals. These studies have consistently shown that the interindividual variability of circadian markers is greater than the intraindividual variability (see for example Refinetti & Piccione, 2005; Romeijn & Van Someren, 2011; Sharma, 1996; Wassmer & Refinetti, 2019).

2.1.2 Aims of the Present Studies

In sum, to the best of our knowledge, none of the existing studies has examined the daily intraindividual variability in mid-sleep (i.e., a marker for chronotype) over a consecutive period of time in a natural setting. The handful of test-retest studies reporting on the temporal stability of chronotype thus far indicate that chronotype is remarkably stable across shorter time scales ranging from two weeks up to one year. However, only few studies have investigated the temporal stability of chronotype over longer periods of time and in different age groups. In order to fill these gaps in knowledge, we present two studies that extend previous research in several ways.

In Study 1, we examined the daily intraindividual variability in chronotype during a consecutive fourteen-day period amongst a sample of undergraduate students from the United Kingdom. More specifically, we were interested in the daily variability of the midpoint of sleep (i.e., midpoint between sleep onset and wake-up) which significantly predicts an individual's DLMO. Similar to previous studies (Urner et al., 2009; Zwart, Smits, Egberts, Rademaker, & van Geijlswijk, 2018), we were not only interested in people's mid-sleep on free days, which is often used to assess chronotype (Roenneberg et al., 2003), but also in people's timing of mid-sleep on workdays. In other words, we aimed to find out how large the intraindividual variability in daily mid-sleep scores is during the period of 14 days and to what extent the daily variability of mid-sleep is influenced by free and workdays. As mid-sleep is composed of sleep onset and wake-up time, we were also interested in the intraindividual variability of these two sleep variables and how they relate to mid-sleep.

We also examined the correspondence between the average daily estimates of mid-sleep both on free and workdays over the period of two weeks and (a) the recall-based estimates of mid-sleep as obtained with the MCTQ (Roenneberg et al., 2003) as well as (b) actigraphy-derived estimates of mid-sleep. Research suggests that global retrospective measures which ask participants to report on their typical behaviour over a certain period of time (e.g., the MCTQ asks about sleep behaviour over the past four weeks) often fail to adequately characterise intraindividual variations over time and therefore, produce more biased estimates than momentary or daily assessments (Shiffman, Stone, & Hufford, 2008). Because studies have shown mixed agreement between objectively and subjectively assessed estimates of sleep (Girschik et al., 2012; Lockley, Skene, & Arendt, 1999), it is important to assess both types of sleep measurement. Thus, another aim of Study 1 was to validate the recall-based mid-sleep estimates on free and workdays as obtained with the MCTQ and the actigraphy-derived measures of mid-sleep against the daily mid-sleep assessments averaged over two weeks.

In Study 2, we investigated the temporal stability of chronotype over a period of 0-1 to 5 years and across different parts of the life span. As we reviewed above, both cross-sectional and a few longer-term longitudinal studies have shown that chronotype can—and mostly does—change across the life span. However, due to a limited age range of their samples, the existing studies have not been able to address the question of whether there is any systematic variation in the longer-term stability of chronotype across the life span. By using a sample of adults with an age range from 18 to 87 years who completed the MCTQ (Roenneberg et al., 2003) twice up to five years apart, we will explore the degree of rank-order stability of mid-sleep on both free and workdays across different stages of adulthood. The pseudodata and scripts for Study 1 as well as the pseudodata and scripts for Study 2 can be downloaded here.

2.2 Study 1: Intraindividual Variability in Mid-Sleep on Free and Workdays Across Two Weeks Method

2.2.1 Participants

A total of 129 undergraduate students from a University in the United Kingdom signed up to take part in the study. We recruited them through the Student Mental Health and Resilience in Transition's[2] (SMaRT) online questionnaire where respondents indicated whether they were interested in participating in an experience sampling study. We also advertised the study on SONA—a system used across the University for advertising and booking into research studies. Of the 129 participants, 13 were not able to participate in the experience sampling study since they could not download the application on their phones that we used for the study. One participant dropped out after the first day of the study. We excluded four participants from the analyses since they did not provide enough information on their sleep to calculate average sleep scores.

As a result, the final sample consisted of 111 University undergraduates, 71 (63.96%) identified as female, 40 (36.04%) as male. Their mean age was 19.71 (*SD* = 1.58) years, ranging from 18 to 32 years. Of those, 104 (93.69%) had actigraphy data available. The dataset has been used in other studies (Das-Friebel et al., 2020; Lenneis, Das-Friebel, Tang, et al., 2020) but it has not been used for the present purpose.

2.2.2 Procedure

Participants took part in a two-week experience sampling study between October 2017 and March 2018. Due to a limited number of actigraphs, only a maximum of 25 participants could partake in the study at a time. Therefore, the data collection took place in five consecutive stages during the abovementioned period.

During each stage of data collection, participants visited the laboratory twice, usually in groups of four to six. During the first introductory session, participants gave their informed consent and filled in an online questionnaire which included sociodemographic questions as well as validated questionnaires about sleep quality, chronotype (i.e., the MCTQ), personality, diet, and affect. They then downloaded an application on their smartphones for the experience sampling study. To link the online questionnaire with the experience sampling data, the participants were given a randomly created unique identification code. At the end of the introductory session, participants received £5. The next morning, the experience sampling study started for the two-week period. If participants had questions, they were advised

[2] `https://warwick.ac.uk/fac/sci/psych/research/lifespan/smart/`

to email the experimenters. After the two-week period, participants came back to the laboratory for a debrief session. They were asked to fill in a short feedback questionnaire, return the actigraphs and collect a remaining honorarium of up to £35 (depending on the number of surveys that they had filled in; one survey was equivalent to approximately £0.63).

The 14-day experience sampling study was conducted with Ilumivu's mobile ecological momentary assessment app (mEMA; `https://ilumivu.com/`) which was compatible with both major mobile operating systems (i.e., Android OS and iOS). Participants were told that each day of the study they would receive two types of surveys—open and momentary surveys. The open survey launched every day at 8 am and was left open for the next 24 hours so that participants could complete the survey any time during the day. They received a reminder to fill it in at the start of the time window. It mainly consisted of questions about the previous day's physical activity, diet, social media usage, and sleep but also about when participants woke up on the day of the survey. Additionally, participants were randomly prompted to fill in a shorter momentary survey five times a day between 8 am and 10 pm from Monday to Friday and between 10 am and 10 pm Saturday and Sunday. At each prompt, participants had 20 minutes to fill in the survey and were advised to complete it as soon as they had received the prompt. During the momentary surveys, participants were asked about their current mood, well-being, what they were doing, and their social media usage. In the present study, only the data from the open survey will be analysed.

Participants were also asked to wear an actigraph for the course of the study. Participants' sleep was recorded with actigraphy the same night following the introduction session whereas the experience sampling study started the next day. We will use the daily actigraphy data for validation purposes.

2.2.3 Materials

Munich Chronotype Questionnaire.

Participants were asked to complete the English version of the MCTQ (Roenneberg et al., 2003) during the first introductory meeting before the 14-day experience sampling study began. The MCTQ consists of 17 items that ask about typical sleep behaviour over the past four weeks separately for workdays and free days in order to take into account our modern lifestyle which often leads to a clash between biological and social clocks (Roenneberg et al., 2019). The MCTQ was designed to assess chronotype as biological phase of entrainment rather than preferences (Roenneberg, 2015; Roenneberg et al., 2003) and it measures chronotype as mid-sleep time on free days (MSF) after correcting for accumulated sleep debt over the week.

In our study, however, we did not correct MSF for sleep debt on workdays because MSF corrected for sleep debt on workdays is not defined as a daily score as it takes into account the sleep duration on free and workdays. It is also problematic to correct MSF for sleep debt on workdays when assessing the validity of the MCTQ scores as the ratio of free and workdays can differ considerably across participants while the correction uses two free days and five workdays (Kühnle, 2006). Furthermore, in a study by Kantermann and Burgess (2017), MSF correlated at $r = .71$ ($p < .001$) with the DLMO, which is currently seen as the gold standard for a circadian phase marker, whereas MSF corrected for sleep debt accumulated on workdays correlated at $r = .68$ ($p < .001$) with the DLMO, indicating that both measures assess chronotype or circadian rhythm equally well. We therefore refer to MSF as chronotype (MSF_{MCTQ}) which we calculated as the midpoint between sleep onset (the time someone falls asleep) and wake-up time on free days. We also computed a midpoint of sleep on workdays (MSW_{MCTQ}) in the same way as the MSF_{MCTQ}. Lower scores of both MSF_{MCTQ} and MSW_{MCTQ} indicate a greater tendency to an early chronotype whereas higher scores indicate a disposition towards a later chronotype (Roenneberg et al., 2003). The MSF_{MCTQ} and MSW_{MCTQ} scores were correlated at $r = .84$ ($p < .001$). The MSF_{MCTQ} ($M = 5.69$; $SD = 1.57$) was significantly higher than MSW_{MCTQ} ($M = 4.49$; $SD = 1.24$), $t(110) = 14.91$, $p < .001$, indicating that people sleep later on free days than on workdays.

Measurement of mid-sleep in the experience sampling study.

Since the MCTQ assesses mid-sleep retrospectively over the period of past four weeks, we had to adjust for this in the experience sampling study. More specifically, on each day of the experiment, participants were asked to answer the following questions: (1) "At what time did you get into bed last night?"; (2) "At what time did you switch off the lights to fall asleep last night?" [*getting ready to fall asleep*]; (3) "How long did it take for you to fall asleep last night?" [*time it takes to fall asleep*]; (4) "At what time did you wake up this morning?" [*wake-up time*]; (5) "Did you use an alarm clock to wake up this morning?" (yes/no) and (6) "Is today a regular working/university day for you?" (yes/no)? We used the last question to differentiate between mid-sleep on workdays and free days. To calculate the daily mid-sleep scores, we first had to calculate sleep onset for each day:

$$sleep\ onset = getting\ ready\ to\ fall\ asleep + time\ it\ takes\ to\ fall\ asleep.$$

Next, we calculated the sleep duration for each day:

$$sleep\ duration = wake\text{-}up\ time - sleep\ onset.$$

The daily mid-sleep scores were calculated using the following formula:

$$mid\text{-}sleep = sleep\ onset + \frac{sleep\ duration}{2}.$$

Overall, there were 1,361 complete daily measurements of mid-sleep across participants out of 1,547 possible measurements (104 participants x 14 days and 7 participants x 13 days due to technical issues), with the overall response rate being 87.98%. Across all participants, we further excluded 21 daily mid-sleep scores due to several reasons[3]. The average number of daily measurements of mid-sleep per participant was 12.25 ($SD = 2.32$), ranging from three to fourteen. The average daily mid-sleep score across the fourteen days across all participants was 5.07 ($SD = 1.27$) which corresponds roughly to 5 am.

Finally, we calculated average daily mid-sleep scores for free (MSF_{ES}) and work (MSW_{ES}) days across the two-week study period. The free and workdays were set differently for each participant, depending on their answers to the question if the day on which they completed the daily measurement of sleep was a regular work-/university day for them or not. The average number of measurements for computing MSF_{ES} was 4.61 ($SD = 2.14$) and 7.45 ($SD = 2.25$) for MSW_{ES}. The correlation between the MSF_{ES} and MSW_{ES} was $r = .87$, $p < .001$. The average daily mid-sleep score on free days (MSF_{ES}; $M = 5.26$, $SD = 1.48$) was significantly higher than on workdays (MSW_{ES}; $M = 4.78$, $SD = 1.23$), $t(107) = 7.34$, $p < .001$.

Actigraphy-derived measurements of mid-sleep.

We used ActiGraph wGT3X-BT devices manufactured by ActiGraph to get objective estimates of mid-sleep. The actigraph recorded information about participants' movements and activity using a 3-axis accelerometer. Participants were not able to indicate on their actigraphs at what time they tried to fall asleep and had gotten out of bed. Therefore, we used the information extracted from the sleep diaries (i.e., the daily open surveys of the experience sampling study) as anchoring points. We calculated the daily mid-sleep scores the same way as in the experience sampling study and then calculated an average score for MSF_{ACT} and MSW_{ACT}. The two scores correlated at $r = .77$, $p < .001$ with each other. The actigraphy-derived average daily mid-sleep score on free days (MSF_{ACT}; $M = 5.65$, $SD = 1.51$) was significantly higher than on workdays (MSW_{ACT}; $M = 4.86$, $SD = 1.18$), $t(100) = 8.44$, $p < .001$.

[3]We excluded 21 instances due to several reasons in the following order: Six instances because participants had indicated the same wake up and going to bed times, one because they went to bed before trying to fall asleep, one because they needed more than five hours to fall asleep, six because their sleep duration was less than or equal to one hour, one because their sleep duration was more than 15 hours, three because their mid-sleep score was more than 15, and lastly three because there was no information available on whether it was a work or free day.

2.3 Results

2.3.1 Intraindividual Variability of Mid-Sleep Over the Period of 14 Days

The main focus of Study 1 was to examine the amount of intraindividual variability in self-reported daily mid-sleep scores across a two-week period. We performed the analyses using linear mixed models employing the afex package (Singmann et al., 2020) in R.

In a first model, we solely compared within- and between-individual variability across the full two-week period. The model which had daily mid-sleep as the dependent variable only contained by-subject random intercepts and no further fixed effects. Results showed that intraindividual variability in daily mid-sleep scores (1.41; $SD = 1.19$) was approximately equal to the interindividual variability in daily mid-sleep scores (1.43; $SD = 1.20$). This can be expressed in terms of an intraclass correlation coefficient (*ICC*) according to which 50.46% of the variance can be explained by between-participant effects. However, the *ICC* is only well-defined for random-intercept-only models and thus we will not be using it in the following model.

Our first model did not allow for the possibility to examine systematic differences in daily mid-sleep scores between free and workdays. More specifically, one could imagine that people's mid-sleep differs systematically between days they have to work versus days they do not have to work when they get up (e.g., compare Friday versus Saturday in a standard European work week)—we call this factor *workday today* (with two levels, workday versus free day). In addition, another factor that might affect mid-sleep is whether the previous day was a free day versus workday (e.g., compare Saturday versus Sunday in a standard European work week)—we call this factor *workday yesterday* (with two levels, workday versus free day).

We coded each day in our data on these two variables based on participants' self-reports and estimated a second mixed model on the daily mid-sleep scores with fixed effects for factors *workday today* and *workday yesterday*, as well as for their interaction. For the random-effects structure, we initially started with the maximal random-effects structure justified by the design (Barr, Levy, Scheepers, & Tily, 2013), which entailed by-participants random-intercepts, by-participant random slopes for the two fixed effects and their interaction, as well as the correlation among the random slopes. Because this model showed a singular fit, we removed the random-slope for the interaction of the two fixed effects (this model still allowed us to retain the correlation among the remaining random-effect parameters).

The test of the fixed effects was based on the Satterthwaite approximation, model predictions are displayed in Figure 2.1. We found significant effects for the two main effects, *workday today*, $F(1, 101.55) = 68.10$, $p < .001$, and *workday yesterday*, $F(1, 101.87) = 8.62$, $p = .004$. Daily mid-sleep scores were later on free days for both factors, that is participants' mid-sleep scores were later when they went to bed and got out of bed on a free day. Furthermore, the effect of *workday today* on daily mid-sleep scores was more pronounced than for *workday yesterday*, meaning that participants' mid-sleep scores were mostly influenced by whether the day they woke up was a free or workday. The interaction between both factors did not reach significance, $F(1, 972.21) = 2.46$, $p = .117$.

Figure 2.1: Violin plot of the mixed model depicting mid-sleep including work and free days today and yesterday. Mean scores across the sample are depicted as bold points together with their 95% confidence intervals. The violin plots depict per participant aggregated data (Study 1).

Finally, we examined the intraindividual variance of daily mid-sleep scores in the second model when considering the effects of free versus workdays. When taking the above elaborated effect of free versus workday into account, the intraindividual variability (1.09; $SD = 1.04$) in daily mid-sleep scores was 0.71 the size of the interindividual variability (1.53; $SD = 1.24$). This indicates that when the effects of free versus workday are controlled for, the daily mid-sleep scores differ less within than between participants.

2.3.2 Intraindividual Variability of Bed-and Wake-Up Times Over the Period of 14 Days

As mid-sleep is calculated as the mid-point between sleep onset and wake-up time, we were also interested to investigate the intraindividual variability in sleep onset and wake-up times. Therefore, we used the same kind of analysis as for mid-sleep. As participants fell asleep before and after mid-night, we subtracted 24 from the times before midnight to have the scores centred on mid-night.

Sleep onset.

The intercept-only model showed that intraindividual variability in daily sleep onset (2.21, *SD* = 1.49) was higher than the interindividual variability (1.91, *SD* = 1.38). According to the *ICC*, 46.37% of the variance was due to between-participant effects. Our final model that included *workday today* and *workday yesterday* showed a significant main effect for *workday today*, $F(1, 99.35) = 25.98$, $p < .001$. There was no significant effect of *workday yesterday*, $F(1, 109.03) = 2.76$, $p = .099$ and the interaction between the two factors was also not significant, $F(1, 1002.07) = 0.00$, $p = .996$. Thus, our results indicate that the participants fell asleep later when it was a free day on the next day. The intraindividual variability of sleep onset (1.90, *SD* = 1.38) was 0.90 times the size of the interindividual variability (2.12, *SD* = 1.46).

Wake-up time.

The intercept-only model indicated that the intraindividual variability in daily wake-up time (1.86, *SD* = 1.36) was larger than the interindividual variability (1.36, *SD* = 1.17). The *ICC* indicated that 42.24% of variance could be explained by between-subject effects. We then came up with models that included *workday today* and *workday yesterday*. Our final model revealed a main effect for *workday today*, $F(1, 110.03) = 73.90$, $p <. 001$) and *workday yesterday*, $F(1,103.69) = 8.68$, $p = .004$. We also found a significant interaction between the two factors, $F(1, 89.41) = 8.01$, $p = .006$. These results indicate that participants woke up later when they both went to bed and woke up on a free day. However, when participants got up on a workday, it did not matter whether it was a free or workday the day before. The intraindividual variability of the wake-up time (1.35, *SD* = 1.16) was 1.05 times the size of the interindividual variability (1.29, *SD* = 1.14).

2.3.3 Correspondence Between the Retrospective Assessments of Mid-Sleep (MCTQ) and Actigraphy-Derived Mid-Sleep with Average Daily Mid-Sleep Scores Over the Period of 14 Days

Finally, we examined the correspondence of retrospective assessments of mid-sleep and actigraphy derived mid-sleep with the average daily mid-sleep scores on free and workdays over the period of two weeks. To this aim, we used the two recall-based mid-sleep scores on free and workdays obtained with the MCTQ before the experience sampling study (MSF_{MCTQ} and MSW_{MCTQ}, respectively) had started, the actigraphy derived scores of mid-sleep (MSF_{ACT} and MSW_{ACT}), and the average scores of mid-sleep on free (MSF_{ES}) and workdays (MSW_{ES}) that were calculated on the basis of the participants' reported daily sleep times during the two weeks of the experience sampling study.

On free days, the retrospective (MSF_{MCTQ}) and the average daily scores of mid-sleep across two weeks (MSF_{ES}) were correlated at $r = .73$ whereas the correlation between the respective scores on workdays (i.e., MSW_{MCTQ} and MSW_{ES}) was r = .79, both correlations significant at $p < .001$. The two correlations did not differ significantly from each other, $z = 1.04$, $p = .300$.

The actigraphy-derived score for mid-sleep on free days (MSF_{ACT}) correlated at $r = .80$ with the average daily scores of mid-sleep across two weeks (MSF_{ES}) whereas the correlation between the respective scores on workdays (i.e., MSW_{ACT} and MSW_{ES}) was $r = .97$, both correlations significant at $p < .001$. The two correlations differed significantly from each other, $z = -6.74$, $p < .001$.

2.4 Discussion

2.4.1 Intraindividual Variability of Mid-Sleep Over the Period of 14 Days

The intercept-only model (first model) showed that about half the variance in daily mid-sleep scores across the period of 14 days can be explained by within-person differences and the other half by between-person differences, suggesting that people's daily mid-sleep scores fluctuate as much within-person from day to day as they do between participants. This is similar to the findings of a fourteen-day experience sampling study by Buysse and colleagues (2009) that also found that there was substantive intraindividual variability in various quantitative and qualitative sleep measures (e.g., bedtime and wake-up time) assessed with sleep diaries and actigraphy.

However, when we included free and workdays into a mixed model, we found that the intraindividual variability in daily mid-sleep was 0.71 times the size of the interindividual variability, so that daily mid-sleep scores differed less within than between participants[4] . This supports the findings of previous studies that have shown that the interindividual variability in circadian rhythms is greater than the intraindividual variability, both in humans and animals (see for example Refinetti & Piccione, 2005; Romeijn & Van Someren, 2011; Selmaoui & Touitou, 2003; Sharma, 1996; Wassmer & Refinetti, 2019). Differently from Selmaoui and Touitou (2003), we tested participants in their natural environments and not in the laboratory which adds to the validity and generalisability of the findings as participants were able to follow their normal work/university and sleep routines during the study period.

Participants' mid-sleep times were affected by free and workdays so that participants had different sleep routines on free days compared to workdays (i.e., that they systematically went to bed and got up later on free days than on workdays), and yet, they had similar mid-sleep scores on free days (i.e., that on all free days they went to bed and got up around the same time) and on workdays (i.e., that on all workdays they went to bed and got up around the same time) during the study

[4]It should be noted though that participants differed in the number of free and workdays they had during the week which might explain why the inclusion of the variables *workday today* and *workday yesterday* made such a difference.

period. The intraindividual variability of sleep onset was 0.90 times the size of the interindividual variability which is similar to the proportion of inter-and intraindividual variability in mid-sleep. However, participants' wake-up times differed more within than between participants which might be due to the fact that wake-up times on workdays are largely predetermined by social and work/university demands. This aligns with previous results that showed that sleep onset is dependent on chronotype on workdays whereas wake-up time is not (Roenneberg et al., 2003). Thus, the variability of mid-sleep cannot fully be explained by the variability of its composing factors.

If we also consider the strong correlations between the mid-sleep scores on free and workdays (both at the level of retrospective (i.e., MCTQ) and daily average measurements, *r*s = .84 and .87, respectively), our findings indicate that people seem to have a general disposition which makes them go to bed either earlier or later, regardless of whether it is a work- or free day. Our final model also showed that participants had a later mid-sleep score when they woke up on a free day and went to bed on a free day. Seizing the opportunity to sleep in on a free day might lead to going to bed later which in turn might also influence one's wake-up time as suggested by the models examining sleep onset and wake-up time. Therefore, when asking about one's mid-sleep on free days, a free day should be defined as a day when one can go to bed and get up on a free day, which would be a Sunday in a typical European work week. In the MCTQ (Roenneberg et al., 2003) for example, participants are asked to differentiate between free and workdays when talking about their sleeping patterns but it is not properly defined what a free day actually means.

2.4.2 Comparison of Retrospective, Actigraphy-Derived, and Average Daily Assessments of Mid-Sleep

The correlations between the retrospective MSF_{MCTQ} and the MSW_{MCTQ} scores with their corresponding average daily mid-sleep scores over the period of two weeks were strong and significant (*r*s = .73 and .79, respectively) and this indicates that the MCTQ (Roenneberg et al., 2003) is a relatively accurate measure to assess participants' sleeping patterns. Participants might already think of their average bedtimes when filling out the questionnaire since they are asked to report on their typical sleep behaviour over the past four weeks. Our findings, however, do not support the results of Santisteban, Brown, and Gruber (2018) who reported that participants depict their sleep times more accurately on free days than on workdays. On the contrary, our findings indicated that the correlations between the retrospective scores of mid-sleep and experience-sampling based average daily assessments of mid-sleep were higher on workdays than on free days. Even though the difference between the two correlations was not significant at $p < .05$, it seems reasonable to assume that one might retrospectively assess one's sleeping patterns during the week better than during free days. During the week, one might have a certain routine at what time to go to bed and get up. However, on free days, one might engage in a variety of different activities that are less predictable.

Kühnle (2006) also reported a high ecological validity of the MCTQ when comparing MSF of the MCTQ with the average MSF score of a six-week long sleep log in people who exhibit a normal chronotype (i.e., the MSF score corrected for sleep debt was between 2.17 and 7.25), $r = .86$ ($p < .001$). However, the correlation was much higher within the normal chronotype spectrum than amongst those with either earlier and later chronotypes (MSF corrected for sleep debt below 2.17 or above 7.25); rs = .56 and .41 (ps < .001), respectively. Our participants were individuals at the end of their adolescence or early adulthood who typically exhibit later chronotypes (Adan et al., 2012), which was also confirmed by the relatively late daily mid-sleep scores we found in our sample. Thus, the ecological validity of the MCTQ might be dependent on chronotype, that is, the variability in MSF may be higher in earlier and later chronotypes than in normal chronotypes. This might make it harder for earlier and later chronotypes to accurately remember their sleep times and thus harder to fill out the MCTQ.

The actigraphy-derived estimates of mid-sleep on free and workdays were highly correlated with the average daily estimates of mid-sleep on free and workdays extracted from the sleep diaries (rs = .80 and .97, respectively). This confirms the assumption that actigraphs and sleep diary derived sleep timings show good correlations (Lockley et al., 1999), indicating that participants can estimate quite well at what time they fall asleep and wake up. The estimations seem to be better on work than on free days as participants seem to better remember the sleep times on workdays.

2.5 Study 2: Longer-Term Temporal Stability of Chronotype Across the Life Span Method

2.5.1 Participants

The participants for Study 2 were a subsample of the Estonian Biobank cohort (currently over 200,000 participants), which is a large-scale population-based sample of the Estonian adults (Leitsalu et al., 2014). A part of the Estonian Biobank cohort has been followed up longitudinally and, in this study, we use a subsample of the cohort who have completed the MCTQ (Roenneberg et al., 2003) twice. Recruitment and data collection were assisted by a unique network of data collectors, i.e., General Practitioners and other medical personnel in private practices and hospitals, but also recruitment offices at the Estonian Genome Center. Participants gave their informed consent which can be found at `https://www.geenivaramu.ee/en/access-biobank`. Doctors conducted a standardised health examination of each participant. Participants gave blood samples and filled in and completed a Computer Assisted Personal Interview (CAPI) on health-related topics and various clinical diagnoses described in the WHO ICD-10 (Leitsalu et al., 2014).

Figure 2.2 depicts a flowchart of how participants from the Estonian Biobank were selected. Overall, 1,111 participants completed the MCTQ twice over the period of one to nine years. The first time they filled it in was between 2007 and 2010, while the second time was between 2009 and 2016. However, we had to exclude participants either at the first (T1) or at the second (T2) point of measurement due to (a) an average sleep duration of shorter than four hours, (b) taking medications that influence sleep (categorised with the World Health Organization's ATC/DDD Index), (c) doing shift work, or (d) missing data. We also excluded ten participants who had completed the MCTQ for the second time more than five years later (i.e., five participants filled in the questionnaires six years apart, two seven years apart, two eight years apart, and one nine years apart). It is a well-known fact that stability and consistency generally decline with longer retest intervals, but we did not have enough participants to test this effect in a more systematic way.

The final sample consisted of 681 participants, 344 (50.51%) of them were female. Their mean age at T1 was 47.73 years (SD = 15.89), ranging from 18 to 87 years. At T1, 69 (10.13%) persons had basic education, 363 (53.30%) completed secondary education/secondary vocational education, and 249 (36.56%) completed higher education.

Fifteen participants (2.20%) completed the MCTQ (Roenneberg et al., 2003) for the second time in the same year (ranging from one to eleven months apart), 48 (7.05%) completed the questionnaires one year apart, 220 (32.31%) two years apart, 293 (43.02%) three years apart, 54 (7.93%) four years apart, and 51 (7.49%) five years apart. On average, the time between two measurements was 2.70 years (SD = 1.05), ranging from zero (40 days) to five years. Due to the small number of participants who filled out the MCTQ in the same year, we combined those with the group that completed the MCTQ one year apart. We performed a one-way ANOVA in order to test whether the groups with different retest intervals differed in terms of age. The results revealed that the five groups did not significantly differ in age either at T1, $F(4,676) = 0.13$, $p = .971$, or at T2, $F(4,676) = 0.77$, $p = .545$. We also performed a chi-square test of independence to compare the frequency of gender and educational level across the six groups. While the groups did not differ in terms of the highest level of educational attainment, $\chi^2(8, N = 681) = 2.53$, $p = .961$, the gender distribution was not equal across the groups, $\chi^2(4, N = 681) = 31.73$, $p <$ .001, so that there were far fewer women than expected in the group of participants who completed the MCTQ two years apart and far more women than expected in the group who were retested five years later. Table 2.2 describes the five groups

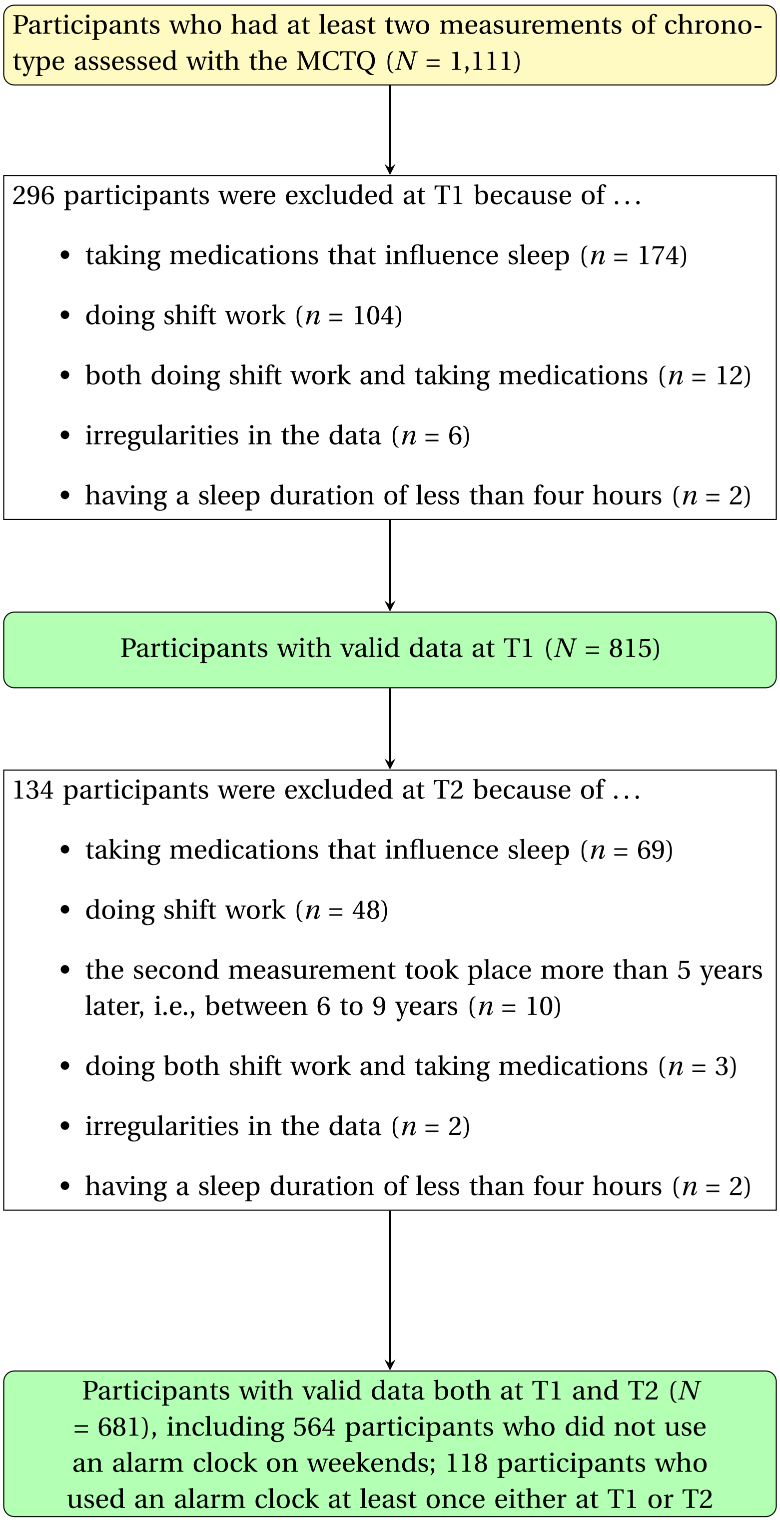

Figure 2.2: Flowchart of the Study 2 sample selection process (Estonian Biobank)

according to their age, gender, and educational attainment at both time points.

2.5.2 Measures

Munich Chronotype Questionnaire (MCTQ).

The Estonian version of the MCTQ by Roenneberg and his colleagues (2003) was used. It is a 17-item retrospective questionnaire that assesses chronotype. Similar to Study 1, the mid-sleep scores on free (MSF) and work (MSW) days were extracted from the questionnaire[5].

2.5.3 Analysis

We used IBM SPSS Statistics 24 for statistical analyses. For each participant, we computed Asendorpf's (1992) coefficient for individual stability both for mid-sleep on free days (MSF) and workdays (MSW) to obtain a measure of intraindividual change in rank-order stability over time (cf. Terracciano, McCrae, & Costa, 2010). This score is calculated as such:

$$i_{12} = 1 - \frac{(z_1 - z_2)^2}{2},$$

where z_1 and z_2 are the z-transformed scores at T1 and T2. The higher the score is, the more stable are the scores between the two measurement points. A negative score indicates that the scores are less stable. The population mean matches the correlation r_{12} between the two assessments. Since the coefficients of individual stability were strongly skewed to the left, we transformed the scores as proposed by Asendorpf (1992):

$$Ti_{12} = \left\{ \frac{\frac{1}{2}\ln\left[\frac{1.001+i_{12}}{1.001-i_{12}}\right] for\ 0\ \leq i_{12} \leq 1}{\ln\left[\frac{1}{1-i_{12}}\right] for\ i_{12} < 0} \right. .$$

We plotted the *t*-transformed scores for MSF and MSW with age and fitted a curve that matched the data best (polynomial curve of two degrees). We divided our participants into age groups to identify how the stability of mid-sleep changes with age. To inform our analyses, we ran a series of hierarchical linear regression models to test whether the *t*-transformed coefficients of individual stability in MSF and MSW were influenced by the age of participants at T1, the quadratic term of age at T1, as well as the time difference between T1 and T2.

[5] For the sake of consistency with Study 1, we did not correct MSF for sleep debt on workdays (MSF_{sc}) in Study 2. However, as suggested by an anonymous reviewer, we also repeated all the analyses using MSF_{sc} and found similar trends. The results of these analyses are reported in Appendix A, Tables A.1 and A.2, and Figures A.1, A.2, A.3, and A.4.

Table 2.2
Sociodemographics and Mean Scores of Mid-Sleep on Free Days and Workdays Across the Five Groups who Completed the Munich Chronotype Questionnaire (MCTQ) Twice Either 0-1, 2, 3, 4, or 5 Years Apart (Study 2).

Year	0-1	2	3	4	5	Total
N	63	220	293	54	51	681
Age at T1 (*SD*)	47.16 (16.81)	47.68 (15.68)	47.90 (16.25)	48.67 (16.25)	46.69 (14.89)	47.73 (15.89)
Age at T2 (*SD*)	48.56 (16.86)	50.33 (15.71)	51.34 (16.31)	52.98 (15.00)	52.14 (14.90)	50.95 (15.96)
Gender						
Females (%)	35 (55.56%)	90 (40.91%)	143 (48.81%)	35 (64.81%)	41 (80.39%)	344 (50.51%)
Education at T1						
Basic (%)	6 (9.52%)	25 (11.36%)	28 (9.56%)	6 (11.11%)	4 (7.84%)	9 (10.12%)
Second-ary/ voca-tional (%)	30 (47.62%)	114 (51.82%)	160 (54.61%)	29 (53.70%)	30 (58.82%)	363 (53.30%)
Higher (%)	27 (42.86%)	81 (36.82%)	105 (35.84%)	19 (35.19%)	17 (33.33%)	249 (36.56%)
Mid-sleep scores						
MSF at T1 (*SD*)	3.83 (1.12)	3.81 (1.26)	3.76 (1.18)	3.81 (1.06)	3.77 (1.16)	3.79 (1.19)
MSF at T2 (*SD*)	3.62 (1.23)	3.82 (1.22)	3.68 (1.20)	3.76 (1.02)	3.58 (1.06)	3.71 (1.18)
MSW at T1 (*SD*)	2.91 (0.83)	2.90 (*0.85*)	2.92 (*0.81*)	2.94 (0.77)	2.82 (0.93)	2.91 (0.83)
MSW at T2 (*SD*)	2.80 (0.78)	2.98 (0.98)	2.92 (0.87)	2.86 (0.73)	2.80 0.90)	2.92 (0.89)

Note. Year = the difference between the first (T1) and the second (T2) completion of the MCTQ in years; MSF = mid-sleep score on free days, MSW = mid-sleep score on workdays; secondary/vocational = secondary education and secondary vocational education. All percentages are within the specific group (year difference when filling out the questionnaires).

2.6 Results

2.6.1 Descriptive Statistics

Across all participants, the average mid-sleep score on free days (MSF) was 3.78 (SD = 1.18) at T1 and 3.72 (SD = 1.18) at T2. The scores did not significantly differ from each other $t(678) = 1.71$, $p = .087$. The average mid-sleep scores on workdays (MSW) also did not differ between T1 (M = 2.91; SD = 0.83) and T2 (M = 2.92, SD = 0.89), $t(678) = -0.33$, $p = .740$. Table 2.2 gives an overview about these scores according to the year difference between filling out the questionnaires. The correlations between MSF and MSW were rs = .70 and .69 at T1 and T2, respectively (both significant at $p < .001$).

2.6.2 Test-Retest Reliabilities of Mid-Sleep Scores for the Groups With Different Retest Intervals

The test-retest correlations for MSF and MSW for the full sample were $r = .66$ and $r = .58$, respectively (both significant at $p < .001$). The test-retest correlations for MSF and MSW for groups with different retest intervals ranging from 0-1 to 5 years are shown in Figure 2.3. Broadly speaking, the retest correlations of MSF and MSW were very similar across the groups with different retest intervals, and varied between .63 (tested 2 years apart) and .70 (tested 3 years apart) for MSF and between .51 (tested 1 year apart) to .65 (tested five years apart) for MSW, respectively. The retest stability of MSF was consistently higher (median retest correlation = .65) than the stability of MSW (median retest correlation = .54) across all five groups with different retest intervals.

2.6.3 Individual and Group-Level Stability of Mid-Sleep Across the Life Span

Finally, we were interested in finding out if and to what extent the individual stability coefficients for MSF and MSW depend on age. Figure 2.4 and Figure 2.5 depict age at the first time of assessment (T1) on the x-axis and the Asendorpf's (1992) t-transformed coefficients of individual stability of MSF (Figure 2.4) and MSW (Figure 2.5) on the y-axis. A t-transformed coefficient of individual stability of 3.8 corresponds to an individual stability coefficient of 1 and a t-transformed coefficient of 2.6 to a coefficient of 0.99. As can be seen from Figure 2.4, the individual stability of MSF increases from young adulthood to early 50s and then starts to decline again from mid-50s onwards. When we fitted a quadratic model on the data (equation of $y = -0.001x^2 + 0.074x - 0.240$), it accounted for 3.53% of the variance in MSF individual stability coefficients compared to the linear model, which only accounted for 1.63%. As for MSW, the individual stability coefficients increase from young adulthood until mid-40s and then decrease from late 40s onwards. When we fitted

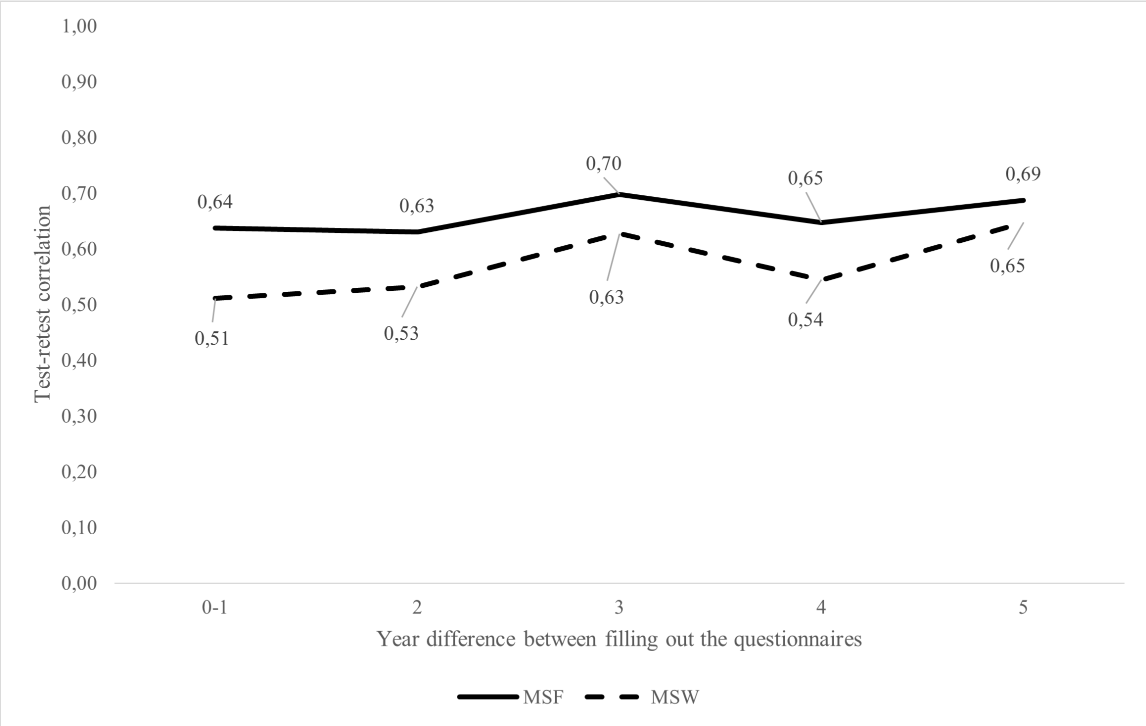

Figure 2.3: Test-retest correlations of MSF (mid-sleep on free days) and MSW (mid-sleep on workdays) according to the time difference between the two measurements (Study 2).

a quadratic model on the data, it accounted for 2.40% of the variance in MSW individual stability coefficients compared to the linear model, which only accounted for 0.27%, with an equation of $y = -0.001x^2 + 0.085x - 0.300$. In any case, the individual stability of mid-sleep both on free and workdays seems to reach its peak in middle age, namely in 40s and 50s.

To further elaborate on how the rank-order stability of mid-sleep on free and workdays is influenced by age, we divided participants into six age categories at T1: 18-25 ($n = 69$), 26-35 ($n = 114$), 36-45 ($n = 134$), 46-55 ($n = 121$), 56 to 65 ($n = 124$), and 66-87 ($n = 119$). We then calculated test-retest correlations for MSF and MSW for each group. Figure 2.6 depicts these test-retest correlations by age group. The rank-order stability of MSF seems to reach a plateau when participants are in late 40-early 50 years of age ($r = .66$, $p < .001$) whereas the rank-order stability of MSW also reaches its peak when participants are 46-55-years old ($r = .74$, $p < .001$) and then decreases again in older participants.

Since stability of psychological traits tends to decline with longer retest intervals (Roberts & DelVecchio, 2000; Terracciano, Costa, & McCrae, 2006) and because the retest interval varied across the participants of our study, we ran a series of hierarchical regression analyses where we predicted the individual stability coefficients (MSF and MSW in separate models) from participant's age and the square of age at T1 (in order to account for both linear and non-linear relationships) when also

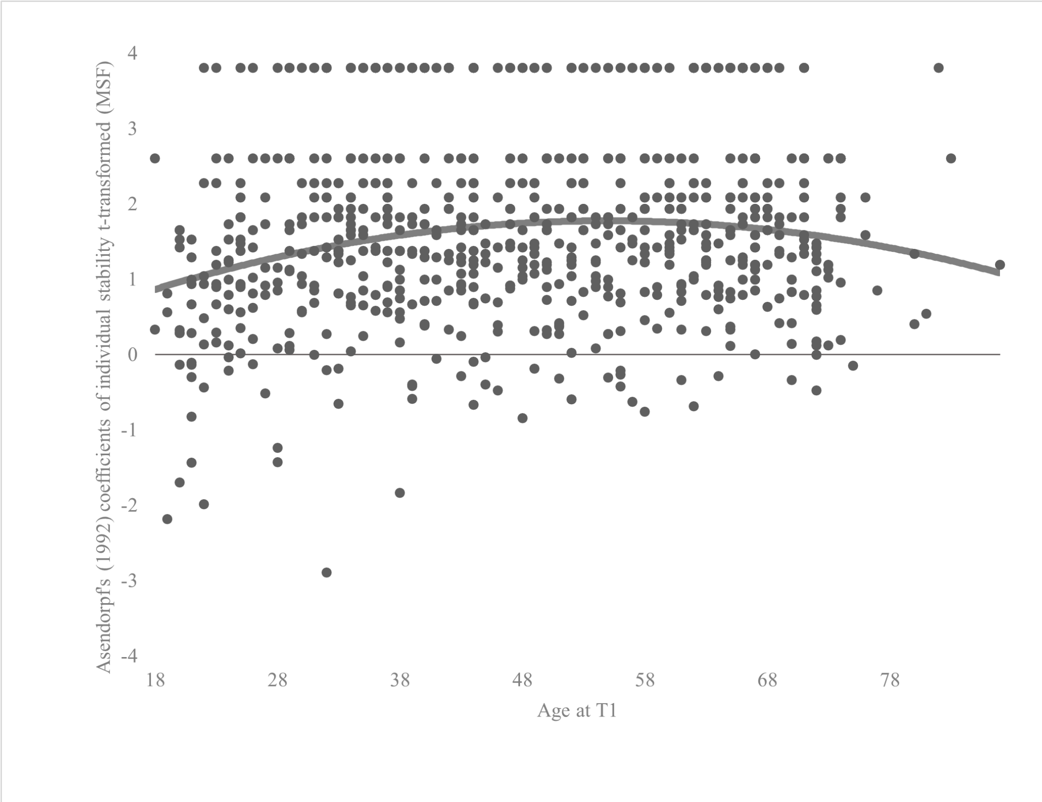

Figure 2.4: Scatterplot depicting age at T1 on the x-axis and the *t*-transformed Asendorpf's coefficient of individual stability of MSF (mid-sleep on free days) on the y-axis (Study 2).

controlling for retest interval. The results of the hierarchical multiple regression analyses for the individual stability of MSF and MSW are shown in Appendix B (Tables B.1 and Table B.2, respectively). In both models, age and age square had a significant effect on the stability of mid-sleep at $p < .001$. Time difference in the retest interval was a significant predictor of the stability of MSF at $p = .045$ but not of the stability of MSW ($p = .477$).

2.7 Discussion

Previous cross-sectional and a few longitudinal studies have shown that chronotype changes across the life span (Adan et al., 2012; Broms et al., 2014; Koskenvuo et al., 2007). We wanted to find out whether there was any systematic variation in the longer-term stability of chronotype across life span. Our results indicate that the rank-order stability of mid-sleep on both free and workdays varies with age and is the highest when participants are in their late 40s to early 50s.

In their most recent critical review of their work, Roenneberg et al. (2019) argued that chronotype should rather be seen as a state and not a trait since *zeitgeber* signals people are exposed to vary in strength and timing. This might indicate

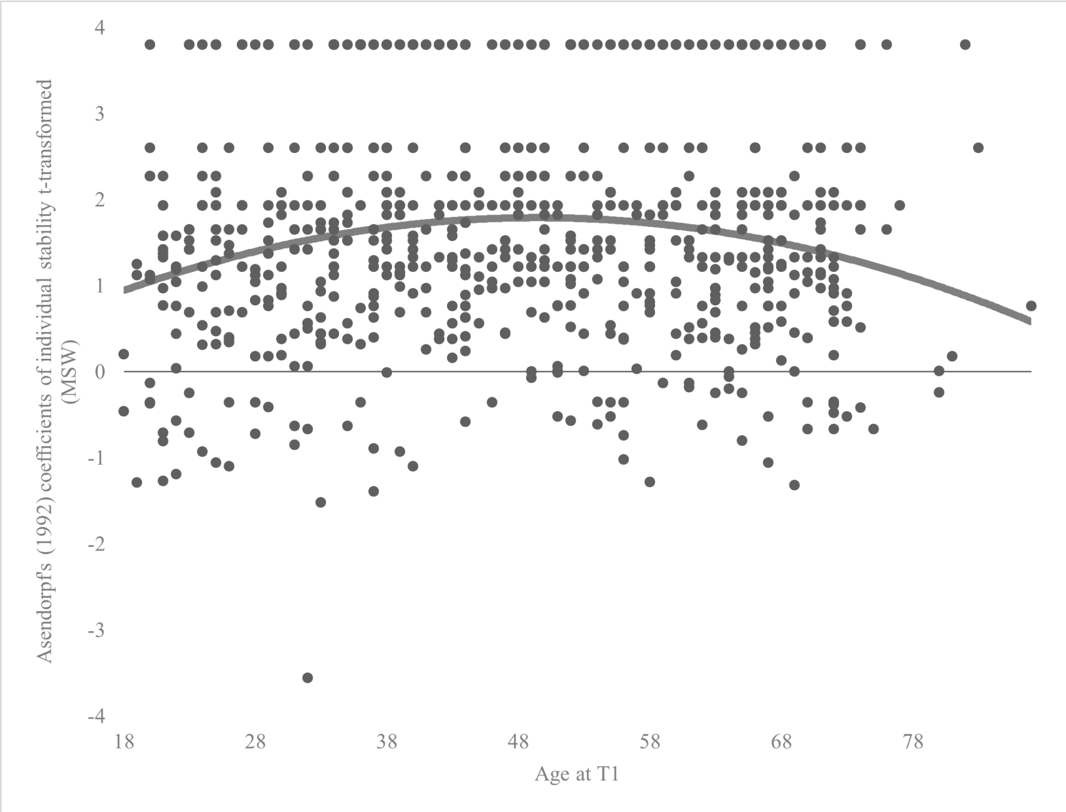

Figure 2.5: Scatterplot depicting age at T1 on the x-axis and the *t*-transformed Asendorpf's coefficient of individual stability of MSW (mid-sleep on workdays) on the y-axis (Study 2).

that the life circumstances of younger and older people may vary more than those of middle-aged participants. During adulthood, humans experience a variety of major life events which in turn might have an impact on their bedtimes. Mid-sleep on free days seems to change the most when participants are at the age of starting something new, for example a job (de Souza, Galina, Florêncio de Almeida, Cortez de Sousa, & Macêdo de Azevedo, 2014), living together with a partner (Hida et al., 2012), or starting a family (Leonhard & Randler, 2009). Therefore, it is not as surprising that the stability of mid-sleep on free days reached a plateau in the age group of 46-55 years of age who most likely had already experienced such life events. Mid-sleep on workdays also reached its peak of stability in the same age group (i.e., 46-55 years) but decreased again in older age groups, meaning that people's sleep habits on workdays seem to become less stable when they reach the retirement age (Hagen et al., 2016) and when their daily routines are no longer determined by work and school hours.

Due to the nature of our study, participants filled out the questionnaire for the second time at different years apart from each other. The results of the hierarchical regression analyses showed that age and its square were more important than the year difference when predicting the stability of mid-sleep on free days and that the

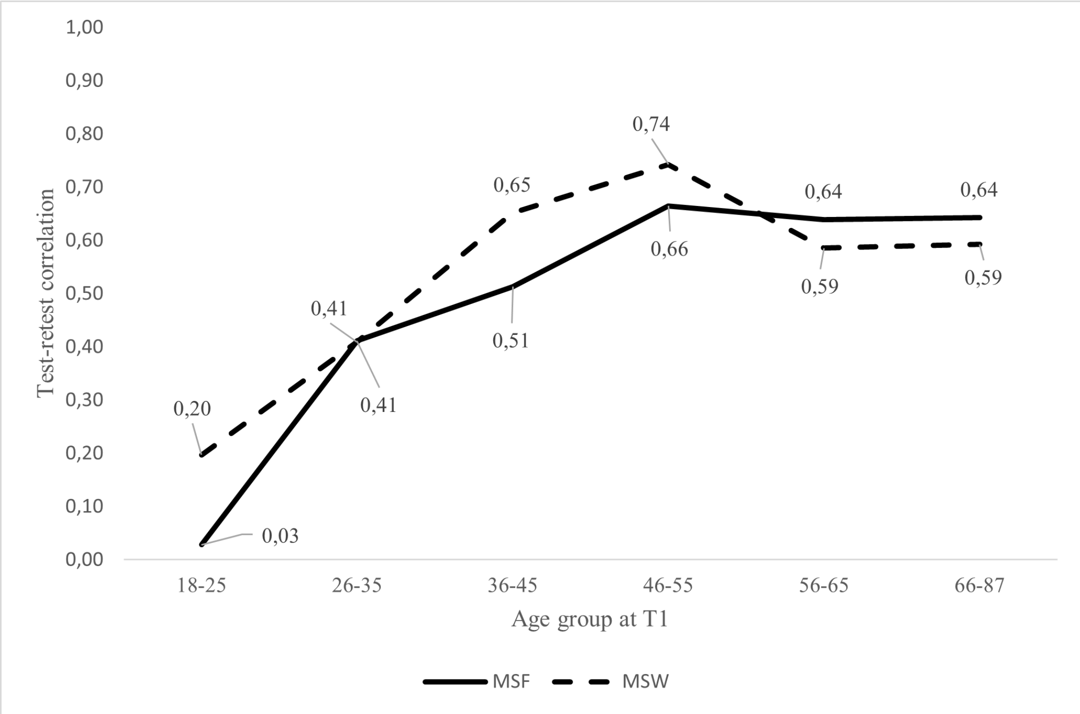

Figure 2.6: Test-retest correlations of MSF (mid-sleep on free days) and MSW (mid-sleep on workdays) by age at T1 (Study 2).

year difference in filling out the questionnaires did not matter when predicting the stability of mid-sleep on workdays. A possible reason for this could be that the time difference between filling out the questionnaires was quite small, ranging from 0 to 5 years.

Overall, both MSF and MSW showed strong test-retest correlations when participants filled out the MCTQ up to five years apart from each other. The retest stability of MSF was higher than the retest stability of MSW at both time points, which shows that one's bedtimes on free days are more stable than those on workdays. Future studies should establish how longer time intervals between filling out the questionnaires will affect the stability of both MSF and MSW.

2.8 General Discussion

Even though chronotype has been a topic of extensive research over the past decades, most studies have used preferential (e.g., The Morningness-Eveningness Questionnaire; Horne & Östberg, 1976) or retrospective recall-based measures of chronotype (e.g., Roenneberg et al., 2003), which typically do not examine the daily intraindividual variability in chronotype. Research in different fields of psychology suggests that global retrospective measures, especially summary measures that ask participants to report on their typical behaviour over several past weeks or months, are often biased because people use mental heuristics to recall information (Shiffman et al., 2008). Study 1 aimed to fill this gap in literature and contribute to a better understanding of intraindividual variability of chronotype over a period of two weeks, as well as to examine correspondence between recall-based estimates of chronotype (i.e., MCTQ) and actigraphy-derived estimates of mid-sleep with average real-time estimates of mid-sleep on free and workdays. Furthermore, only few studies have investigated the temporal stability of chronotype; the majority of those studies evaluated the test-retest reliability of chronotype questionnaires during relatively short periods of time while not bearing in mind how age might affect the temporal stability of chronotype (see for example Di Milia, Adan, Natale, & Randler, 2013; Kühnle, 2006; Smith et al., 1989). Thus, Study 2 examined the stability of mid-sleep over longer periods of time while also considering the effect of age.

When the daily variability in mid-sleep was examined across the study period of two weeks (Study 1), we found that the intraindividual variability was about equal to the interindividual variability in daily mid-sleep scores (*ICC* = 50.46%), meaning that there was as much variability between participants' daily mid-sleep scores as in within each participant. However, when the effect of free versus workday was considered, people's mid-sleep scores fluctuated more across than within participants. Our findings also speak for the relatively high levels of intraindividual consistency in chronotype, meaning that even though people have different mid-sleep points in work and free days, they tend to have a routine of going to bed and getting up on workdays and a different routine on free days. We also found that waking up on a free day has the biggest influence on one's mid-sleep—not surprisingly, people wake up later on free days than on workdays—but interestingly, going to bed on a free day also delays one's mid-sleep, meaning that people go to bed and wake up the latest when both the day they go to bed and the day they wake up are free days.

The recall-based retrospective mid-sleep scores on free (MSF) and work (MSW) days extracted from the MCTQ (Roenneberg et al., 2003) correlated highly with the respective average mid-sleep scores from the experience sampling study (*r*s = .73 to .79). This is consistent with previous research (Kantermann et al., 2015; Kühnle, 2006; Santisteban et al., 2018) and speaks for high ecological validity of the MCTQ. It seems though that our participants were slightly more accurate in retrospectively estimating their sleep times on workdays than on free days which could be explained by the fact that there are more restrictions and less flexibility in sleep times due to university-related responsibilities (e.g., classes, seminars etc.) on weekdays compared to free days (cf. Paine & Gander, 2016), and thus, sleep times can be more accurately recalled. However, it should be noted that the sleeping times assessed in the MCTQ asked about the four weeks before the start of the experience study and therefore did not overlap with the sleeping times extracted from the experience sampling study. This means that the bedtimes extracted from the MCTQ could have also differed from the average bedtimes during the course of the experience sampling study. As we found high correlations between the average daily self-reported mid-sleep scores and the average mid-sleep scores assessed with actigraphy during the same period of fourteen days, we can be quite certain that participants can estimate well at what times they fall asleep and wake up. However, the correlations might be this high because we anchored the actigraphy-derived sleep times on the sleep times extracted from the sleep diaries.

Study 2 contributed to important insights into the change and stability of chronotype over a longer period of time and across different stages of life span. We found relatively high retest correlations for MSF and MSW when examining the retest stability of mid-sleep during the periods of zero/one to five years. The median retest correlations of MSF and MSW at T1 with T2 across different time periods were .65 and .54, respectively, which are comparable (if slightly lower) to the retest stability coefficients of the Big Five personality traits assessed in middle adulthood with a testing interval of three to ten years (Hampson & Goldberg, 2006; Terracciano et al., 2010). Our estimates were, however, a bit lower than those reported in previous studies when participants' chronotype was tested twice during one to 24 months using mostly preferential questionnaires of chronotype or morningness and eveningness (see for example Caci et al., 2000; Di Milia et al., 2013; Greenwood, 1994; Griefahn et al., 2001; Kühnle, 2006; Smith et al., 1989; Wood et al., 2009). The lower retest stability indicators in our study could be due to a longer time span between the two measurements since it is known that the stability of psychological traits declines with longer test-retest intervals (Roberts & DelVecchio, 2000; Terracciano et al., 2006). As our testing interval varied from 0-1 to 5 years, we also conducted hierarchical linear regression analyses to examine the effects of age and the year difference on the stability of mid-sleep. The results showed that age was more important than the year difference between two measurements in predicting the stability of mid-sleep on free days. The stability of mid-sleep on workdays was only affected by age and not the year difference between the measurements.

Interestingly, across the whole sample, the retest stability of mid-sleep on free days (.66) was greater than on workdays (.58) over the periods of up to five years. During a longer time interval, several life circumstances might change due to changing opportunities and constraints characteristic of different stages in life (Heckhausen, Wrosch, & Schulz, 2010). These could have impacted one's mid-sleep on workdays, for example, having children and their entry into school, getting a promotion, or retiring.

One of the novel aspects of Study 2 was to examine the retest stability of chronotype across different stages of life span. Even though mid-sleep on free days and workdays remained relatively stable over a period of up to 5 years, the retest stability varied greatly in different age groups: the retest stability coefficients both for mid-sleep on free and workdays were the lowest when participants were in late teens and early twenties and the highest when participants were in their late 40s to early 50s. Even though mid-sleep fluctuates little within young adults over a period of two weeks (Study 1), the temporal stability coefficients of mid-sleep are very low when participants are tested twice over much longer periods of time (Study 2). Interestingly though, the stability of mid-sleep on free days reaches a plateau and levels off when participants are in their late 40s to early 50s whereas the stability of mid-sleep on workdays decreases again when people reach the retirement age. This seem to suggest that the differences in the stability of mid-sleep across the life span are likely not solely due to biological age effects but also to social life-cycle effects (e.g., finishing school, finding a job, getting married, settling down, retiring, etc.) that are intertwined with the biological process of aging (Glenn, 2003). These findings are confirmed by individual level stability analyses (see Figure 2.4 and Figure 2.5), which provided further evidence in support of the view that mid-sleep stability changes over the life span. Overall, both group and individual level analyses clearly indicate that when examining the stability of chronotype or mid-sleep, the effect of age (either biological or social in nature) strongly needs to be considered.

2.8.1 Limitations and Future Research

Our approach was not without limitations though. Firstly, the participants from both studies differed in age. The participants from Study 1 were university students whereas the participants from Study 2 were part of a large-scale sample of Estonian adults ranging from 18 to 87 years in age at T1. Therefore, the results of Study 1 might not be applicable to older participants whereas we did consider the effect of age in Study 2.

In Study 1, we were able to show that intraindividual variability in mid-sleep is a lot smaller than interindividual variability when the type-of-day variable was controlled for. This can be partly explained by the difference in the amount of free and workdays our participants reported. Future research could use experience sampling methodology of mid-sleep using a representative population over a longer period of time to generalize our findings of intraindividual stability of chronotype. It would also be interesting to explore whether early and late chronotypes show a different intraindividual variability in mid-sleep.

When examining the temporal stability of mid-sleep across the life span in Study 2, we compared the stability of mid-sleep in different age groups that consisted of different participants. Thus, future studies need to confirm our findings by applying a longitudinal approach that would allow to examine the intraindividual change of the stability of mid-sleep in the same individuals across the life span (cf. Terracciano et al., 2010). Furthermore, long-term longitudinal studies will be necessary to explore how life circumstances and other possible factors influence one's mid-sleep.

In sum, our studies have given important insights on the intraindividual variability and temporal stability of mid-sleep. Using experience sampling and longitudinal methodologies we were able to complement the weaknesses of cross-sectional studies. Our results show that mid-sleep varies less within than between participants when the effect of free and workdays is controlled for and that the stability of mid-sleep of both mid-sleep on free and workdays is largely dependent on age. However, future research is needed to investigate how intraindividual variability of mid-sleep is depended on chronotype and how the temporal stability of mid-sleep systematically changes with age.

Chapter 3

The Five-Factor Model of Personality Domains, Facets, and Nuances Is Associated With Chronotype at Both the Phenotypic and Genetic Level

Abstract: In Chapter 2, I showed that age influences the stability of mid-sleep. Another factor that has been linked to diurnal preferences, but not yet to sleep timing (i.e., chronotype), is personality. The present study advances the field by examining the relationships between chronotype and the five-factor model (FFM) of personality traits at both the phenotypic and genetic level. We used data from 2,515 adult participants (M_{age} = 45.76 years; 59% females) from the Estonian Biobank cohort who filled in the the NEO Personality Inventory-3 (informant reports also) and the Munich Chronotype Questionnaire (MCTQ). DNA samples were also available for them. Results of the hierarchical linear regression analyses showed that higher Conscientiousness and lower Openness to Experience were significant predictors of earlier chronotype when controlling for age, gender, education, and season when the MCTQ was completed. At the level of facets, we found that it was more straightforward (A2) and excitement-seeking (E5), yet less self-disciplined (C5) people, who were more likely to be later chronotypes. The item-level Polypersonality score was correlated with chronotype at $r = .28$ ($p < .001$). Polygenic scores (PGSs) for personality domains did not significantly predict chronotype but the PGS for chronotype significantly predicted the Polypersonality score. 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 chronotype must be partly due to genetic factors. However, future studies with PGSs of better predictive

validity are necessary to further refine the relationship.

3.1 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 generalisation—there are substantial differences among individuals in their sleep timings (chronotype) and preferences (morningness-eveningness), which are related to many important behavioural outcomes (Keller, Zöschg, Grünewald, Roenneberg, & Schulte-Körne, 2016; Lucassen et al., 2013; Rahafar, Mohamadpour, & Randler, 2018; Randler, Horzum, & Vollmer, 2014; Susman et al., 2007; Urbán, Magyaródi, & Rigó, 2011). Morningness-eveningness has also been linked to personality in past research (eg., Lipnevich et al., 2017; Randler, Schredl, & Göritz, 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, Pereira-Morales, & Forero, 2017). Differently from previous research, the focus of the present study is on actual sleep timing (chronotype). 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") is associated with chronotype at both the phenotypic and genetic level.

3.1.1 Personality

Personality refers to recurrent behaviours, thoughts, or feelings that set apart individuals from some or others (Asendorpf & Rauthmann, 2020; Johnson, 1997). Personality is often hierarchically organised by the five-factor model (FFM) of general personality structure (McCrae & John, 1992; Widiger, 2015). The FFM divides personality into five domains: Neuroticism, Extraversion, Openness to Experience, Conscientiousness, and Agreeableness which are the sum of six facets each (Costa & McCrae, 1992).

Neuroticism refers to an enduring tendency to experience negative emotional states. Those who score high on Neuroticism are likely to feel anxious, guilty, angry, or depressed, and tend to respond poorly to environmental stress (Widiger, 2009). Extraversion describes one's tendency to experience and exhibit positive affect, assertive behaviour, and engage in social behaviour (Wilt & Revelle, 2009). Openness describes that there are individual differences in imagination, sensitivity to aesthetics, depth of feeling, preference for novelty, cognitive flexibility, and social and political values (Sutin, 2015). Persons who score low on Agreeableness can be described as hard-headed, sceptical, proud, and competitive, whereas those who score high on the domain might be seen as compassionate, good-natured, and eager to cooperate and avoid conflict (McCrae & Costa, 2003). Conscientiousness describes socially prescribed impulse-control that enables task-and goal-oriented behaviours such as following norms and rules, planning, organising, and prioritising tasks, and thinking before acting (John & Srivastava, 1999).

In the current study, we use the NEO-PI-3 by McCrae et al. (2005) to assess personality. It consists of 240 items personality and assesses personality on the FFM domains and 30 facets. It is a revised version of the NEO-PI-R (Costa & McCrae, 1992). Table 3.1 gives an overview of of the NEO-PI-3 domain and facets which are the same as for the NEO-PI-R (Costa & McCrae, 1992).

Table 3.1
Facets of the Five Factor Model Personality Domains (NEO-PI-3)

Neuroticism	Extraversion	Openness	Agreeableness	Conscientiousness
N1: Anxiety	E1: Warmth	O1: Fantasy	A1: Trust	C1: Competence
N2: Angry Hostility	E2: Gregariousness	O2: Aesthetics	A2: Straight-forwardness	C2: Order
N3: Depression	E3: Assertiveness	O3: Feelings	A3: Altruism	C3: Dutifulness
N4: Self-Conscientiousness	E4: Activity	O4: Actions	A4: Compliance	C4: Achievement Striving
N5: Impulsiveness	E5: Excitement Seeking	O5: Ideas	A5: Modesty	C5: Self-Discipline
N6: Vulnerability	E6: Positive Emotions	O6: Values	A6: Tender-Mindedness	C6: Deliberation

Note. NEO-PI-3 = NEO Personality Inventory-3 (McCrae et al., 2005)

3.1.2 Associations of Chronotype and Morningness-Eveningness With the FFM Personality Traits

Earlier studies that have explored the associations between diurnal preferences (i.e., morningness-eveningness) and personality traits have found somewhat mixed and even contradictory results which partly, may be due to different conceptualisations of personality (Lipnevich et al., 2017). Moreover, even though most studies have operationalised morningness-eveningness as a one-dimensional construct, there are also some more recent studies that measure morningness and eveningess on two separate dimensions (Lipnevich et al., 2017), making the comparison of empirical results published in different studies difficult.

When summarising 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 with 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, Yang, Song, Du, & Zhang, 2016; Duggan, Friedman, McDevitt, & Mednick, 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 when FFM personality traits were correlated with morningness-eveningness, all five 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, the study 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 (e.g., Barclay et al., 2010; Paine, Gander, & Travier, 2006; Randler et al., 2017; Roenneberg & Merrow, 2007; Walker, Kribs, Christopher, Shewach, & Wieth, 2014), and personality traits (e.g., McCrae et al., 2004; Schmitt, Realo, Voracek, & Allik, 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.

As described above, most of the studies have examined 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 behaviour (Mõttus, 2016; Paunonen & Ashton, 2001; Paunonen, Haddock, Forsterling, & Keinonen, 2003). For example, it has been reported that there is a direct pathway between Self-discipline (C5), a facet of Conscientiousness and health behaviour (Hagger-Johnson & Whiteman, 2007). The lowest level of the personality trait hierarchy is conceptualised 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, Mõttus, Allik, Esko, & Realo, 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 two constructs.

3.1.3 Genetic Mechanisms of the Personality-Chronotype 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. Both chronotype and the FFM personality traits are rooted in biology and are substantially heritable—according to twin studies, about 50% of the variance in chronotype (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. In recent decades, the results of behavioural 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). Recent GWAS, for instance, have identified 351 loci for chronotype (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 chronotype (Hill et al., 2019). As explained in Chapter 1, the effect sizes of SNPs in predicting complex traits like chronotype and personality are usually very small (Gratten et al., 2014) and more variance can be explained when considering the effects of SNPs jointly. The sum of SNPs weighted by their effect size estimates are often called genome-wide polygenic scores (PGSs) and 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 whether phenotypic variability in chronotype is associated with PGSs for personality domains. Since we do not know enough about the causality of the relationship between chronotype and personality on the basis of existing research, we next examined whether the phenotypic variability in personality traits is associated with PGS for chronotype. Should there be significant correlations between PGSs for personality domains and self-reported chronotype, and/or between PGS for chronotype and phenotypic personality traits, it would indicate a polygenic overlap between these constructs (Cheesman et al., 2019; Turkheimer et al., 2014). Significant correlations between PGS for chronotype and phenotypic personality traits would provide further support to the hypothesis that the observed genetic variance in personality traits may at least partly reflect a general genetic pull (cf. Mõttus, Realo, Vainik, Allik, & Esko, 2017).

3.1.4 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 conceptualised and assessed with the MCTQ (Roenneberg et al., 2007, 2003) 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 personality-chronotype relationship, we secondly investigate whether a genetic predisposition for personality is associated with chronotype using PGSs for personality, and vice versa, that is, whether PGS for chronotype is associated with the phenotypic variability in the FFM personality traits.

3.2 Method

3.2.1 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 twenty 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 both 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, Das-Friebel, Singmann, et al., 2020; Realo et al., 2015; Realo, Van der Most, et al., 2017) but it has not been used for the present purpose.

3.2.2 Measures

Munich Chronotype Questionnaire

Consistent with Study 2, Chapter 2, 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.

Unlike in Chapter 2 but 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}) which needs to be calculated when one's sleep duration on free days is greater than on work days using the following formula: $MSF_{\text{sc}} = MSF - \frac{(SD_{free} - SD_{work})}{2}$, 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.[1] 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 = 0.56, 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).

NEO Personality Inventory-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

[1] 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 C.1 of Appendix C.

of the Estonian NEO PI-R questionnaire (Costa & McCrae, 1992; Kallasmaa, Allik, Realo, & McCrae, 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 5-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 observer-reports are shown in Appendix C (Table C.2). Self- and informant-reports of the NEO-PI-3 personality traits correlated with each other in the expected magnitude (Connolly, Kavanagh, & Viswesvaran, 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 since 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 depicted in Tables C.3 to C.8. 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 shown in Table C.2.

Polygenic scores (PGSs)

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, Lewis, & O'Reilly, 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 twenty principal components with Plink 1.9. We standardised the PGS so that they were more comparable with each other, with a mean of 0 and standard deviation of 1.

PGSs for personality domains. The PGS for Neuroticism was trained on the GWAS results from 390,278 individuals of the UK Biobank (Nagel et al., 2018) whereas the PGSs for Extraversion, Openness, Agreeableness, and Conscientiousness were trained on GWAS results from 59,225 participants from a privately held personal genomics and biotechnology company called 23andMe (Lo et al., 2017).

In the UK Biobank survey, Neuroticism was measured with twelve dichotomous (yes/no) items taken from the Eysenck Personality Questionnaire Revised Short Form (Eysenck, Eysenck, & Barrett, 1985). The 23andMe respondents filled out the 44-item Big Five Inventory (John, Donahue, & Kentle, 1991; John, Naumann, & Soto, 2008). However, 23andMe did not make the full GWAS results available to the public; instead, they only reported the first 10,000 SNPs.

PGS for chronotype. The PGS for chronotype was trained on chronotype GWAS results (Jones et al., 2019) 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 towards morningness.

PGS parameters. We used $p = 0.001$ cutoff and PRSice default clumping criteria (r^2 threshold for clumping = .1; clumping distance = 250kb from both sides). INFO criterion was set to >.90 for UK Biobank traits; this column was not available for the personality traits from the 23andMe study (i.e., for Extraversion, Openness, Agreeableness, and Conscientiousness). After matching with available variants in the data and clumping, PGS for Neuroticism was based on 5,213 variants, for Extraversion on 537 variants, for Openness on 700 variants, for Agreeableness on 1,033 variants, and for Conscientiousness on 814 variants. The PGS for chronotype was based on 2,298 variants.

The pseudodata and the scripts can be downloaded here.

3.2.3 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 utilised 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 hours), and 391 (15.55%) completed the questionnaire between May and July (summer; average daylight 17.5 hours).

3.2.4 Statistical Analyses

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, Gomez Grajales, and Kurkiewicz (2013) were met.

Polygenic score prediction of personality and chronotype

We used R 3.6.1 for the analyses. First, we examined how much variance personality PGSs and chronotype PGS explain in their respective phenotypic traits. Second, we predicted in separate analyses a) MSF_{sc} from the PGSs for the FFM personality domains and b) phenotypic NEO-PI-3 personality scores from the PGS for chronotype. 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 twenty principal components as described above, and lastly, the PGSs for personality domains or for chronotype.

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.

3.3 Results

3.3.1 Preliminary and Validation Analyses

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}, $F(2, 2176) = 4.91$, $p = .007$, $\eta^2 = .005$. 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].

Development of a weighted personality item score (Polypersonality score)

We used the glmnet package (J. Friedman et al., 2019) 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 summarise personality, cognition, and brain effects on health outcomes (Benning, Patrick, Blonigen, Hicks, & Iacono, 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 C.9. 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 were 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.

Predictive validity of the PGSs

Next, we examined how much variance PGSs for personality domains and the PGS for chronotype explain in their respective phenotypic traits.

Personality. Only the PGS for Neuroticism was able to predict its corresponding phenotypic NEO-PI-3 score (self-and informant reports combined) at $p < .001$ (see Table C.10). In total, the twenty principal components, sociodemographic variables, and the PGS for Neuroticism were able to explain 6.40% of the variance in Neuroticism, $f^2 = .08$ with a standardised regression coefficient of 2.59. Adding the PGS for Neuroticism to the initial model containing the twenty principal components and sociodemographic variables increased the explained variance by 1.24%. The PGS for Neuroticism was also a significant predictor of all six phenotypic facet scores of Neuroticism at $p < .001$. The other four PGSs for personality—i.e., PGS for Extraversion, Openness, Agreeableness, and Conscientiousness—did not significantly predict the respective phenotypic scores of NEO-PI-3 personality domains or any of their six facets at $p < .05$.

Chronotype. The PGS for chronotype predicted phenotypic MSF_{sc} at $p < .001$ with a standardised regression coefficient of -.12 (as mentioned above, the chronotype 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 twenty principal components and sociodemographic variables only increased the explained variance by 0.91%.

3.3.2 Associations Between the FFM Personality Traits and Chronotype

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 shown in Table 3.2.

Table 3.2
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]**

Continued on next page

Table 3.2 continued from previous page

	MSF_{sc}
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 on free days 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 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 3.3 gives an overview of the model, including regression coefficients with confidence intervals, standardised regression coefficients (β) 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 (β = -.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}.

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

Table 3.3

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			0.161				0.35	
F for Change in R^2			84.82	<.001			106.21	<.001
Effect size f^2			0.20				0.55	

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.

$p < .05$ 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 3.2).

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 C.11 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.

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}.

3.3.3 Regressing Phenotypic Chronotype on the PGS for the FFM Personality Traits

Next, we examined the extent to which the PGS for the FFM personality domains can predict phenotypic chronotype (MSF_{sc}). We first used separate models to predict MSF_{sc} from one personality PGS at a time. We then came up with a joint model to predict MSF_{sc} from the five PGSs of the FFM personality traits. Table 3.4 gives an overview of the separate models and the joint model which also includes the regression coefficients of the personality PGS that were used in the model.

In the separate models, the PGSs for Neuroticism, Extraversion, Openness to Experience, Agreeableness, and Conscientiousness were not significant predictors of MSF_{sc} at $p < .05$. The joint model showed that adding the five PGS for personal-

Table 3.4

Standardised Regression Coefficients of the Polygenic Scores (PGS) of Personality Predicting Self-Reported Chronotype While Controlling for the Twenty Principal Components and Sociodemographic Variables. The Separate Models Take Into Account one PGS of Personality at a Time Whereas the Joint Model Uses the PGS of the FFM Together to Predict Self-Reported Chronotype.

	Separate models			Joint model	
	Regression coefficient	*p*	Amount of explained variance	Regression coefficient	*p*
Neuroticism	-.05	.130	0.001	-.05	.140
Extraversion	.03	.278	0.001	.03	.278
Openness	-.03	.356	0.000	-.03	.400
Agreeableness	-.01	.751	0.000	-.01	.741
Conscientiousness	.00	.849	0.000	.00	.852
Adjusted R^2 baseline model			.323		
Adjusted R^2 full model			.324		

Note. FFM = Five Factor Model of Personality. 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 personality PGS. *P*-values were adjusted for the false discovery rate.

ity together to the baseline model of the twenty principal components, the chip, sociodemographic variables and season increased the adjusted R^2 from 32.26% to 32.40%. That is, all five PGS for the FFM personality domains explained 0.14% of the variance in MSF_{sc}, $f^2 = .50$. Again, no personality PGS were significant predictors of MSF_{sc} at $p < .05$.

3.3.4 Predicting Phenotypic FFM Personality Traits From the PGS for Chronotype

Finally, we predicted all NEO-PI-3 personality domains, facets, and nuances (i.e., the Polypersonality score) from the PGS for chronotype using a series of multiple regression analyses (see Table 3.5).

The PGS for chronotype 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 standardised regression coefficient of -.02, explaining 0.71% of the variance of the Polypersonality score.

3.4 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 showed that the PGS of chronotype predicted the Polypersonality score, indicating that that the relationship between personality and chronotype must also be due to genetic factors as there are no shared environmental factors associated with a PGS (Cheesman et al., 2019).

3.4.1 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

Table 3.5

Standardised Regression Coefficients of the Polygenic Scores (PGS) for Chronotype Predicting the NEO-PI-3 Domain and Facet Scores, and Polypersonality Score While Controlling for the Twenty Principal Components and Sociodemographic Variables

	Regression coefficient	*p*	Amount of explained variance
Neuroticism	.27	.858	0.000
N1: Anxiety	.14	.580	0.000
N2: Angry Hostility	.05	.872	0.000
N3: Depression	.10	.580	0.000
N4: Self- Conscientiousness	.09	.580	0.000
N5: Impulsiveness	-.08	.635	0.000
N6: Vulnerability	-.01	.972	0.000
Extraversion	-.56	.580	0.000
E1: Warmth	-.17	.235	0.001
E2: Gregariousness	-.14	.580	0.000
E3: Assertiveness	-.01	.972	0.000
E4: Activity	.04	.924	0.000
E5: Excitement-Seeking	-.20	.210	0.001
E6: Positive Emotion	-.10	.609	0.000
Openness to Experience	-.71	.235	0.001
O1: Fantasy	-.14	.534	0.001
O2: Aesthetics	-.26	.193	0.002
O3: Feeling	.03	.924	0.000
O4: Actions	-.08	.580	0.000
O5: Ideas	-.31	.105	0.003
O6: Values	.03	.872	0.000
Agreeableness	-.02	.972	0.000
A1: Trust	-.09	.580	0.000
A2: Straightforwardness	-.12	.580	0.000
A3: Altruism	-.04	.872	0.000
A4: Compliance	-.01	.972	0.000
A5: Modesty	.21	.193	0.002
A6: Tender-Mindedness	.02	.924	0.000
Conscientiousness	.42	.580	0.000
C1: Competence	-.02	.924	0.000
C2: Order	.14	.580	0.000
C3: Dutifulness	.00	.972	0.000
C4: Achievement Striving	.12	.580	0.000
C5: Self-Discipline	.22	.193	0.002
C6: Deliberation	-.03	.924	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 chronotype PGS. *P*-values were adjusted for the false discovery rate.

also Extraversion, to be a significant predictors of morningess/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, John, Gosling, & Potter, 2011).

One of the novel aspects of our study was analysing 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 colours 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 that 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, reverse coded)—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.

3.4.2 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 behaviour (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 behaviours, 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, García, & García, 2003), and are therefore more likely to engage in alcohol use and risky sexual behaviour, including a higher frequency of one-night stands (Justus, Finn, & Steinmetz, 2000). Similar to chronotype, Openness has been found to reach its peak when adolescents are transitioning into young adulthood (Lüdtke, Roberts, Trautwein, & Nagy, 2011; Vecchione, Alessandri, Barbaranelli, & Caprara, 2012). However, open individuals tend to feel younger than their chronological age, with this association growing stronger with increasing age (Stephan, Demulier, & Terracciano, 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, Gosling, & Pennebaker, 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, is highlighted by their similarity in relationships to health and mortality—people low in Conscientiousness and later chronotypes are more likely to die to younger (H. S. 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 behaviours whereas they avoid or reduce behaviours 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.

3.4.3 Genetic Mechanisms Underlying the Relationships Between Personality and Chronotype

In addition to the pathways explained above, it is also possible that personality and chronotype might be related because of their shared genetic etiology. Before proceeding with main analysis, we first examined how much variance the PGS for personality and chronotype explain in their respective phenotypic traits. Our results showed that the PGS for Neuroticism explained 1.66% of the variance in phenotypic Neuroticism whereas the other four PGSs for personality domains (i.e., PGSs for Extraversion, Openness, Agreeableness, and Conscientiousness) did not significantly predict their respective phenotypic scores of NEO-PI-3 personality domains or any of their six facets at $p < .05$. The PGS for chronotype explained 0.91% of variance in MSF_{sc}, even though the PGS was trained on circadian preferences (i.e., morningness-eveningness) and not on chronotype as conceptualised and measured by the MCTQ.

There might be two explanations for why personality PGSs did not predict phenotypic personality scores. First, PGSs for personality have been consistently less predictive in explaining variance in their target traits than cognitive PGSs such as PGSs for education and intelligence (Okbay et al., 2016; Smith-Woolley et al., 2019). In a recent study by Smith-Woolley and colleagues (2019), the PGS for Neuroticism only explained 0.73% of the variance in phenotypic Neuroticism, despite the fact that there is more known about the genetics of Neuroticism than of any other FFM personality trait (Realo, Van der Most, et al., 2017; Sanchez-Roige, Gray, MacKillop, Chen, & Palmer, 2018). Likely, larger GWAS samples are needed for computing more predictive PGSs. The second reason may be related to the fact that the PGS for Neuroticism was trained on the GWAS results from the UK Biobank (Nagel et al., 2018), where Neuroticism had been measured with the Eysenck Personality Questionnaire Revised Short Form (Eysenck et al., 1985). In contrast, the PGSs for Extraversion, Openness, Agreeableness, and Conscientiousness were trained on GWAS results from 23andMe (Lo et al., 2017) that were based on the Big Five Inventory (John et al., 1991, 2008). Thus, either the difference in the measurement instrument between the two GWAS, or that 23andMe had fewer participants and only made the first 10,000 SNPs available for our analyses, could account for why PGSs for four personality domains failed to explain any variance in their respective phenotypic traits.

Thus, it is perhaps not so surprising that none of the PGSs for the NEO-PI-3 personality domains significantly predicted MSF_{sc} when also controlling for all other relevant variables. Moreover, when we predicted the five phenotypic NEO-PI-3 domains and 30 facets from the PGS for chronotype, we also did not find any significant associations. However, the PGS of chronotype was able to significantly predict the item-level Polypersonality score, explaining 0.71% of its variance. This indicates that chronotype, at least to some extent, is genetically linked with personality. In order to improve the predictive validity of personality PGSs, larger GWAS are needed in order to identify more validated loci for complex traits (Park et al., 2010), such as Extraversion, Openness, Agreeableness, and Conscientiousness and their facets.

3.4.4 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). In 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 work (Abbott et al., 2017), or social factors, 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, Wittmann, Nowak, Birkholz, & Angerer, 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. Thus, they would be ready to fall asleep at a more appropriate time.

3.4.5 Limitations, Conclusions, and Future Research

Of course, this 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 C.1) which might have influenced our results. Finally, as already highlighted above, the PGS for Extraversion, Openness, Agreeableness, and Conscientiousness did not show predictive validity which might be the reason why we did not find an association between genotypic personality and phenotypic chronotype.

This study has contributed to a more thorough understanding of the relationship between personality and chronotype. 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 chronotype was only able to regress on the Polypersonality score, the Polypersonality score seems to be related the most with chronotype. Future research should focus on the generalisability 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. We used PGSs for personality domains and chronotype to better understand the possible genetic underpinnings of the relationship between the two constructs and our findings indicate that personality and chronotype seem also to be related on a genetic level. Subsequent studies will be necessary to understand the shared genetic mechanisms between the two constructs as well as the causality of their relationships.

Chapter 4

The Impact of Sleep on Next Day's Subjective Well-Being

Abstract: In Chapters 2 and 3, I examined factors that influence (the stability of) sleep timing. The current study goes a step further by examining the influence that sleep timing and other sleep indicators have on subjective well-being (SWB). Previous research has associated sleep with SWB, but less is known about the underlying within-person processes. In the current study, we investigated how self-reported sleep (satisfaction, duration, onset latency, social jetlag) and actigraphy-measured sleep efficiency of the previous night influence the next day's SWB and its three components (i.e., positive affect, negative affect, and life satisfaction). One hundred and twelve participants from a UK University took part in a two-week experience sampling study using a smartphone application. Results showed that higher than personal average sleep satisfaction was a significant predictor of all three components of next day's SWB at $p < .005$ and that longer than personal average sleep duration was associated with higher positive affect on the next day ($p = .045$). Significant associations with SWB were not detected for other indicators of sleep. When including all sleep variables into a joint model, only sleep satisfaction remained a significant predictor of all components of SWB. We also found that shorter than average person sleep duration combined with higher than personal average sleep satisfaction was associated with higher life satisfaction the next day. Our results indicate that it is the evaluative component of sleep—sleep satisfaction—that is most consistently linked with next day's SWB. Thus, sleep interventions aimed at enhancing sleep satisfaction may prove useful in improving students' SWB and mental health.

4.1 Introduction

Sleep is not only associated with physical health and mortality (Cappuccio, D'Elia, Strazzullo, & Miller, 2010) but also with one's subjective well-being (SWB; e.g., Lemola, Ledermann, & Friedman, 2013; Ong, Kim, Young, & Steptoe, 2017; Tang, Fiecas, Afolalu, & Wolke, 2017). SWB is often conceptualised as consisting of three independent components: positive affect, negative affect, and life satisfaction (Diener, 1984; Tay & Diener, 2011). Positive affect (PA) refers to the extent to which an individual subjectively experiences positive moods (Miller, 2011), whereas negative affect (NA) involves feelings of emotional distress (Watson et al., 1988). The third component of SWB—life satisfaction—involves an evaluative judgment of one's life (Diener, 1984). Previous research has shown that the strength of relationships among the three components of SWB may depend on age, personality traits and cultural values (Kuppens, Realo, & Diener, 2008; Kööts-Ausmees, Realo, & Allik, 2013). Moreover, the affective and cognitive components of SWB have been shown to be influenced by different causes (Diener, 2013) and to be differently related to various outcome variables (Realo, Johannson, & Schmidt, 2017). Therefore, one might lose valuable information when combining the three variables (Diener, 2000). For the reasons outlined above, we will also measure in our study all three components of SWB separately from each other as the relationship between sleep and SWB might be different depending on which component of SWB is used.

4.1.1 Relationship Between Sleep and SWB

The relationships between sleep and (the three components of) SWB have been addressed in a plenitude of studies. As we focus on five dimensions of sleep in the current study, we will only review the relationship between those and SWB here.

Sleep onset latency

There are very few studies that have investigated the relationship between sleep onset latency (i.e., the time it takes to fall alseep; both subjectively and objectively measured) and SWB. A cross-sectional study that assessed actigraphic sleep onset latency over seven days found that sleep onset latency was not related to SWB (Lemola et al., 2013) whereas another cross-sectional study reported no relationship between self-reported sleep onset latency and life satisfaction (Gaina et al., 2005). However, difficulties in initiating sleep is also a symptom of insomnia (Roth, 2007) which has been negatively related to SWB (Hamilton et al., 2007).

Sleep duration

The importance of sleep duration for SWB has been identified in sleep deprivation studies. The findings of experimental studies show that sleep deprived adolescents report less PA (Dagys et al., 2012; Rossa, Smith, Allan, & Sullivan, 2014) but no change was found in negative affect (Rossa et al., 2014). When looking into how relative sleep loss affects well-being, an experience-sampling study by Wrzus, Wagner, and Riediger (2014) found that in adolescents, shorter than average sleep duration led to worse affective well-being on the next day whereas in adults over 20 years of age, both shorter and longer sleep duration than average led to worse affective well-being. However, the results of an experience sampling study in medical residents showed that sleep loss increased one's levels of PA on the next day (Zohar, Tzischinsky, Epstein, & Lavie, 2005). In a panel study, Piper (2016) observed that life satisfaction was the highest when participants slept eight hours on a typical weekday. A study by Lemola and colleagues (2013) did not find an association between sleep duration and SWB but found that the variability in sleep duration was related to SWB.

Mid-sleep/social jetlag

A cross-sectional study by Diaz-Morales and colleagues 2015 examined the relationships between chronotype and mood in a sample of high school students and found that evening-oriented students showed worse mood compared to other chronotypes. In a comprehensive review, Adan et al. (2012) also reported a few cross-sectional studies that linked morningness with greater life satisfaction and greater SWB. The association between low psychological well-being, i.e., depressed mood, and later chronotypes has been explained by social jetlag (Wittmann et al., 2006). For example, later chronotypes might go to bed late and still wake up early on the next day to go to work, hence not getting enough sleep during the week and thus experiencing social jetlag.

Sleep quality/satisfaction

A systematic review by Ong et al. (2017) reported consistent evidence of an association between PA and subjectively or objectively rated sleep quality in healthy populations. Findings of the review of cross-sectional and longitudinal studies indicate that higher levels of trait/state PA are independently associated with better sleep quality in non-clinical samples of adults. A cross-sectional study found that in adolescents, the relationship between positive and negative affect seems to be stronger with sleep quality than with sleep duration (Shen, van Schie, Ditchburn, Brook, & Bei, 2018).

Sleep efficiency

Mixed results have been found regarding the relationship between sleep efficiency (Reed & Sacco, 2016, i.e., percentage of time spent asleep in bed since attempting to fall asleep) and SWB. A validation study by Jackowska, Ronaldson, Brown, and Steptoe (2016) using both cross-sectional and longitudinal methods, found that actigraphy-derived sleep efficiency was negatively related to PA, positively related to NA, and not related to life satisfaction. Yet, a three-day long actigraphy study by Giradin, Kripke, and Ancoli-Israel (2000) reported no relationship between sleep efficiency and SWB in an adult population.

Studying within-person effects

The studies that have examined the relationships between sleep and SWB are mostly cross-sectional studies (see for example Dagys et al., 2012; Diaz-Morales & Escribano, 2015; Gaina et al., 2005; Rossa et al., 2014). A pitfall of cross-sectional research is that it only allows one to investigate between-person variability and thus does not consider within-person processes, which means that group-level effects cannot be applied to individuals within that group (Curran & Bauer, 2011). This discrepancy has often been illustrated with the following medical example. Even though people who exercise more tend to have a lower risk of heart attacks (i.e., between-person effect), heavy physical exertion can trigger a heart attack, particularly in individuals who usually exercise less (i.e., within-person effect; see for example Curfman, 1993; Mittleman et al., 1993). Hence, there is growing awareness that greater emphasis must be placed on the study of within-person processes (Curran & Bauer, 2011), and this can only be accomplished through studying intraindividual differences in repeated measures data (see for example Molenaar, 2004). Van Dongen, Vitellaro, and Dinges (2005) showed that there is interindividual variability in human sleep parameters, indicating that people differ in the number of hours they sleep, in their sleep quality, or mid-sleep (chronotype). Furthermore, both the amount and quality of sleep also fluctuate within people, for example, there is a substantive amount of intraindividual (daily) variability (Buysse et al., 2009) in various sleep parameters that might affect SWB. Components of SWB also show a substantive amount of intraindividual variability (Mill, Realo, & Allik, 2016; Willroth, John, Biesanz, & Mauss, 2020).

4.1.2 Aims of the Present Study

In the present study, we address limitations of previous research by applying experience sampling methodology in examining how daily fluctuations from one's average sleep indicators impact the next day's SWB (i.e., PA, NA, and life satisfaction). Both experience sampling and longitudinal studies have shown that it is predominantly sleep that affects SWB (Kalak, Lemola, Brand, Holsboer-Trachsler, & Grob, 2014; Simor, Krietsch, Koteles, & McCrae, 2015; Totterdell, Reynolds, Parkinson, & Briner, 1994; Triantafillou, Saeb, Lattie, Mohr, & Kording, 2019), and not the other way around. This directionality has also been supported by experimental studies linking sleep deprivation to lower SWB (Dagys et al., 2012; Rossa et al., 2014). Therefore, we also assume that in our study sleep is influencing SWB and not the other way around.

We chose university students as our participants as they are a homogeneous group, which minimised the effect of age and comorbid health conditions. Differently from a study by Wrzus and colleagues (2014), we not only use a single sleep indicator (sleep duration) as this does not grasp sleep as a multidimensional experience (Buysse, 2014). To this effect, we measured several subjective and objective sleep indicators in our study, including sleep duration, sleep onset latency, social jetlag, sleep satisfaction (a component of sleep quality), and sleep efficiency. Our study addressed two other gaps in literature that, to our knowledge, have not been examined before. First, we examined daily fluctuations of (absolute) social jetlag (i.e., the absolute difference between mid-sleep on free days and daily mid-sleep). Second, to look at sleep indicators both independently and jointly, we examined joint models that use all five sleep indicators to explain one component of SWB at a time, simulating the complexity of sleep in real life.

We hypothesised that longer than average sleep onset latency, either shorter or longer sleep duration, and higher absolute social jetlag are associated with worse SWB, whereas higher than average sleep satisfaction and sleep efficiency are associated with better SWB on the next day. We pre-registered all our hypotheses before the analyses of the data, which can be found here.[1]

4.2 Method

We used the same dataset as in Study 1 of Chapter 2.

4.2.1 Participants

We recruited 129 undergraduate students from the University of Warwick to take part in the study. Of those, 13 were not able to participate since they experienced difficulties in downloading the mobile phone application that we used for the experience sampling. One participant dropped out at the beginning of the study. We excluded 22 daily sleep instances in the experience sampling study due to several reasons, which resulted in excluding all instances of one participant.[2] We also excluded one participant who was 32-years old as chronotype is dependent on age (Adan et al., 2012). Finally, our model excluded one participant because there was insufficient data available (i.e., valid sleep data for only one day and only one valid momentary survey).

The final sample consisted of 112 participants. Their average mean age was 19.60 (*SD* = 1.06) years, ranging from 18 to 22 years. Seventy-two (64.29%) identified themselves as female and 40 (35.71%) as male. Of those, 104 (92.86%) had actigraphy data available.

[1] Please note that I accidentally duplicated Hypothesis 7- therefore PA in Hypothesis 9 should be replaced with life satisfaction. There is also a problem with the numbering from Hypothesis 9 onwards, but the contents of the hypotheses remain the same.

[2] We excluded 22 instances due to several reasons in the following order: Six instances because participants had indicated the same wake-up and going-to-bed times, one because they went to bed before trying to fall asleep, one because they needed more than five hours to fall asleep, six because their sleep duration was less than or equal one hour, one because their sleep duration was more than 15 hours, three because their mid-sleep score was more than 15, and lastly four because there was no information available on whether it was a work or free day.

4.2.2 Procedure

The procedure of the experience sampling study has already been described in the Procedure section of Study 1 of Chapter 2. In the current study, we are using data from both momentary and opens surveys, as well as actigraphy which are described briefly below.

For the experience sampling part of the study, we used Ilumivu's mobile ecological momentary assessment app (mEMA) since it was compatible with both major mobile operating systems (i.e., Android OS and iOS). Participants received two types of surveys a day—open and momentary surveys. Participants were prompted to fill in the open survey every day at 8 am, and although they could respond to it any time over the next 24 hours, they were asked to fill it in as soon as possible to avoid memory biases. It consisted mainly of retrospective questions about the previous day and night, such as physical activity, social media usage, and sleep. However, it also included a few questions about the current day, such as whether it was a free day or a workday. Over the course of the study, participants were asked to fill in fourteen open surveys (one survey a day). However, due to technical problems with the app, seven participants received only thirteen prompts; hence the total number of prompts was 1,561 (105 x 14 + 7 x 13). Altogether, participants responded to 1,352 prompts, yielding a response rate of 86.61%. The valid answers per participant ranged from one to fourteen open surveys (M = 12.07, SD = 2.69). For the momentary survey, participants were prompted at five varying timepoints in a day to fill it in. The prompt arrived either between 8 am and 8 pm (Mondays to Fridays) or between 10 am and 10 pm (Saturday and Sunday), with a minimum of one hour between the prompts. Participants were instructed to complete each survey as soon as possible, although they had a maximum of 20 minutes to respond before the survey closed. The momentary surveys asked participants about their current mood, well-being, what they were doing, their social media usage, etc. The complete list of questions asked in the open and momentary surveys can be found at the Open Science Framework. In theory, participants were able to fill in 70 (14 x 5) momentary surveys during the course of the study. However, due to technical issues, some of the momentary prompts were not released, leading to an average number of prompts of 68.48 (SD = 6.18), ranging from 30 to 70 prompts. Overall, participants responded to 4,533 momentary prompts, yielding a response rate of 59.10%.

Participants were asked to wear a waterproof actigraph for the entire duration of the study. We advised them to wear it as much as possible, but that they should take it off in situations when they could harm themselves, others, or the device (e.g., when practicing martial arts).

4.2.3 Measures

Self-reported daily sleep measures (assessed with open surveys) and actigraphy

Participants were asked to keep an electronic sleep diary. Through the open survey, participants were asked to report each day about the previous night's sleep times (i.e., time they went to bed, time they got ready to fall asleep, time it took them to fall asleep, wakeup time, getting up time), which was based on the MCTQ (Roenneberg et al., 2003). Using these sleep times, we were able to calculate the sleep parameters. Participants also had to indicate how satisfied they were with their sleep the previous night. Since participants wore an actigraph when they were sleeping, we could calculate objective sleep parameters such as sleep efficiency. As reported in the pre-registration here, we only included those sleep indicators in the study that correlated at less than $r = .30$ with each other in order to ensure only low to moderate multicollinearity (Baguley, 2012). Based on these preliminary findings, the following variables were used in the current study:

Sleep onset latency. We asked participants to indicate how long it took them in minutes to fall asleep after they had gotten ready to fall asleep and switched off the lights.

Sleep duration. Sleep duration was calculated as the time difference between sleep onset

$$sleep\ onset = switch\ off\ lights + time\ it\ takes\ to\ fall\ asleep$$

and wake up time.

Absolute social jetlag. Absolute social jetlag is usually calculated as the absolute value of the difference between mid-sleep on free days (MSF) and workdays (MSW; Wittmann et al., 2006). It can be interpreted as the amount of time people's social and biological clocks differ from each other. The score is also given in hours, and the higher the score is, the more the two clocks differ from each other. A score of 0 indicates that people are not experiencing a misalignment of their social and biological clocks. Mid-sleep is defined in the MCTQ as the mid-point between sleep onset and wakeup time (Roenneberg et al., 2003), i.e.,

$$mid\text{-}sleep = sleep\ onset + \frac{sleep\ duration}{2}.$$

As we were interested in daily ratings of absolute social jetlag, we calculated daily absolute social jetlag as the absolute value of the difference between mid-sleep on free days from the MCTQ (MSF_{MCTQ}) and daily mid-sleep scores (MS_{daily}), i.e.,

$$daily\ absolute\ social\ jetlag = |MSF_{MCTQ} - MS_{daily}|$$

MSF_{MCTQ} can be seen as an indicator of chronotype (Roenneberg et al., 2003). Participants of the current study filled out the MCTQ during the introductory session the day before the experience sampling study started.

Sleep satisfaction. Participants were asked to indicate on a four-point scale (from 1 = "very dissatisfied" to 4 = "very satisfied") how satisfied they were with their previous night's sleep. Subjective sleep satisfaction is a component of subjective sleep quality (Lemola et al., 2013), which has been related to insomnia, sleep duration, sleep onset latency, and anxiety (Ohayon & Zulley, 2001). The terms sleep satisfaction and sleep quality are often used interchangeably (Harvey, Stinson, Whitaker, Moskovitz, & Virk, 2008). Sleep quality judgments seem to be determined by not only what happens during sleep, but also what happens after the sleep period (Ramlee et al., 2017) and therefore include an evaluative component (Ramlee et al., 2017).

Actigraphy-based sleep efficiency. We used ActiGraph wGT3X-BT devices manufactured by ActiGraph to get objective estimates of sleep efficiency. The actigraph recorded information about participants' movements and activity using a 3-axis accelerometer. We calculated sleep efficiency via the ActiLife 6 software using the Sadeh scoring algorithm. It is considered appropriate for younger populations because it was developed using participants ranging from ten to 25 years (ActiGraph Software Department, 2012). We measured sleep efficiency as the percentage of time spent asleep in bed since attempting to fall asleep (Reed & Sacco, 2016). Someone with a score of above 85% is typically seen as a good sleeper (see for example D. J. Taylor et al., 2018). Participants were not able to indicate on their actigraph at what time they tried to fall asleep and gotten out of bed. Therefore, we used the information extracted from the sleep diaries as anchoring points.

Subjective well-being (assessed with momentary surveys)

Positive and negative affect. We measured positive and negative affect using five positive mood items (happy, enthusiastic, content, relaxed, attentive) and five negative mood items (upset, annoyed, bored, sad, worried). We selected items from the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) and James Russell's (1980) Circumplex Model of Affect, including items that were low and high on arousal as well as unpleasant and pleasant feelings. Participants were asked to indicate on a five-point scale (from 1 = "not at all" to 5 = "too a large extent") how they felt at the moment. The items were presented in randomised order.

Exploratory factor analysis of positive and negative affect items. In order to investigate the underlying structure of the ten emotional items that were included in the study, we first ran a principal component analysis with varimax rotation across all participants and instances. The scree plot clearly indicated a two-factor solution that explained 55.78% of the total variance. The factor loadings of the first factor, that we identified as Positive Affect, ranged from .63 (relaxed) to .77 (happy), whereas the factor loadings of the second factor (Negative Affect) ranged from .48 (bored) to .81 (upset). The secondary loadings of all ten emotion items were smaller in size than their primary loadings and ranged from -.36 (sad) to .08 (attentive).

Based on the findings of the exploratory factor analysis, the mean scores of the five positive and five negative items as measures of positive (PA) and negative affect (NA) were computed, respectively, with higher scores indicating greater levels of respective mood. Since participants filled out these items up to five times a day, we calculated a daily mean score of PA and NA. The Cronbach's α of PA and NA across all participants and measurement instances were .81 and .75, respectively.

Life satisfaction. We measured life satisfaction using a single item, namely, "All things considered, how satisfied are you with your life at the moment?". Participants were asked to rate this item on a 10-point scale from 1 = "extremely dissatisfied" to 10 = "extremely satisfied" using a continuous slider. Participants were asked to indicate their satisfaction with life five times a day, and a daily mean score of life satisfaction (LS) was used in further analyses.

4.2.4 Statistical Analysis

To investigate within-person compared to between-person effects, we first person-mean centred the following independent variables (Wang & Maxwell, 2015): self-reported sleep onset latency, sleep duration, sleep satisfaction and sleep efficiency over the two weeks. This means that for each self-reported sleep indicator, we subtracted the average two-week scores of each participant from their daily scores. For example, if a person slept eight hours on average during the two-week period but slept 9 hours on the first and 7.5 hours on the second day of the study, their person-mean centred scores for Day 1 and Day 2 were 1 and -0.5, respectively. In the first example, a hypothetical slope estimate for sleep duration of 0.1 for the dependent variable LS would indicate that, if a person reports a sleep duration that is 1 hour higher than their average sleep duration, it is associated with a LS that is on average 0.1 higher than their average mean life satisfaction on the LS scale from 0 to 10. As explained above for daily absolute social jetlag, we centred the scores on mid-sleep on free days (absolute value) that we extracted from the MCTQ (Roenneberg et al., 2003).

We used the afex package (Singmann et al., 2020) in R to test our hypotheses when applying linear mixed models that are robust in handling missing data (Baayen, Davidson, & Bates, 2008). We tested our model terms with the Satterthwaite method (Keselman, Algina, Kowalchuk, & Wolfinger, 1999). All initial mixed models included by-participant random intercepts and by-participant random slopes for all independent variables that varied within-participants. This constituted the maximal random effect structure justified by design (Barr et al., 2013). The initial models also included correlations among random slopes, which we removed first in case of convergence problems. When the model showed further convergence problems (e.g., a singular fit), we iteratively reduced the random-effects structure, beginning with removing the highest order random slopes, until the model converged successfully (Singmann & Kellen, 2019).

The pseudodata and scripts can be found here.

4.3 Results

4.3.1 Descriptive Statistics

Since our data are based on repeated within-subject records, the descriptive statistics presented here are based on the mean scores of each participant during the 14-day-period. During the 14 days, participants on average needed 19.80 (SD = 13.50) minutes to fall asleep. Their mean sleep duration was 7.41 (SD = 1.01) hours. Their average mid-sleep across all days was 5.07 (SD = 1.27; i.e., 5:04 am). The average score of mid-sleep on free days (M = 5.56; SD = 1.48, i.e., 5:33 am) was significantly higher than on workdays (M = 4.78; SD = 1.22, i.e., 4:46 am), $t(109) = 8.72$, $p < .001$. The average absolute social jetlag score over the 14 days was 0.90 (SD = 0.77), whereas the mean absolute social jetlag score extracted from the MCTQ at the beginning of the study was 1.25 (SD = 0.76). The two scores did not differ from each other significantly, $t(109) = 3.86$, $p = .355$. Participants were quite satisfied with their sleep, indicated by an average score of 2.85 (SD = 0.41) out of a 4-point-scale. Their average actigraphy-based sleep efficiency was 80.80% (SD = 6.79).

The mean score of PA over the two-week period was M = 2.74 (SD = 0.52), with average daily scores ranging from 1.60 to 4.46, and the mean score of NA was M = 1.64 (SD = 0.44), with average daily scores ranging from 1.01 to 2.93, both on a scale from 1 to 5. Participants rated their life satisfaction as 6.06 (SD = 1.70) on a scale from 1 to 10 over the two-week period, with average daily scores ranging from 1.41 to 9.85.

Table 4.1 depicts the correlations among the sleep indicators and the components of SWB. As already explained in the Measures section, we only chose those sleep indicators in our study that correlated the most at $r = .30$ with each other to avoid multicollinearity. Among the sleep indicators, the highest correlation was found between sleep onset latency and sleep satisfaction, $r = -.30$ ($p < .001$) and the lowest correlation between sleep efficiency and MSF_{MCTQ}, $r = .01$ ($p = .922$). In SWB, PA correlated with NA at $r = -.52$ and with LS at $r = .82$ whereas NA and LS correlated at $r = -.63$ with each other, all correlations significant with $p < .001$.

Table 4.1

Correlation Matrix of the Sleep Variables and Components of SWB

	Sleep onset latency	Sleep duration	Mid-sleep on free days (MCTQ)	Absolute social jetlag (ES)	Absolute social jetlag (MCTQ)	Sleep satisfaction	Sleep efficiency	PA	NA	LS
Sleep onset latency	1									
Sleep duration	-.08	1								
Mid- sleep on free days (MCTQ)	.18	-.18	1							
Absolute social jetlag (ES)	-.24*	-.04	.16**	1						
Absolute social jetlag (MCTQ)	-.04	-.13	.57***	.21*	1					
Sleep satisfaction	-.30**	.26**	-.15	.15	-.10	1				
Sleep efficiency	.03	-.14	.01	.03	.17	.05	1			
PA	-.34**	.11	-.06	.07	-.04	.44***	-.03	1		
NA	.26**	-.10	.22*	-.06	.18	-.25**	.01	-.52***	1	
LS	-.30**	.05	-.16*	.05	-.09	.38***	.00	.82***	-.63***	1

Note. *** $p < .001$, ** $p < .01$, * $p < .05$. ES = Experience Sampling (14-day average); MCTQ = Munich Chronotype Questionnaire. PA = Positive Affect. NA = Negative Affect. LS = Life Satisfaction. Scores are based on mean scores of each participant during the 14-day-period (except for scores from the MCTQ). SWB = Subjective well-being.

4.3.2 Mixed Models Predicting PA, NA, and LS From Sleep Variables

Our primary aim was to examine how individual fluctuations in sleep (i.e., sleep onset latency, sleep duration, absolute social jetlag, sleep satisfaction, and sleep efficiency) are related to SWB on the next day. We ran separate models for each independent and dependent variable at a time, resulting in fifteen different models. We also came up with three joint models that included all five sleep variables predicting one component of SWB at a time (i.e., PA, NA, and LS).

Single models

Table 4.2 gives an overview of the model estimates *b*, *t*-values, degrees of freedom, and *p*-values of the single models.

Self-reported sleep onset latency, absolute social jetlag, and actigraphy-measured sleep efficiency did not significantly predict PA, NA, or LS the next day ($ps > .48$). Sleep duration was a significant predictor of PA, $b = 0.02$, $t(54.16) = 2.06$, $p = .045$, indicating that a longer sleep duration than one's 14-day average predicted higher PA the next day. However, sleep duration was not a significant predictor of NA and LS ($ps > .40$). Figure 4.1 gives an overview of the three models.

Self-reported sleep satisfaction was a significant positive predictor of PA, $b = 0.14$, $t(58.39) = 6.25$, $p < .001$, a negative predictor of NA, $b = -0.07$, $t(83.01) = -3.00$, $p = .004$, and a positive predictor of LS, $b = 0.24$, $t(74.51) = 4.41$, $p < .001$. The results suggest that if one is more satisfied with one's previous night's sleep than on average across the 14-day period, one experiences an increase in their levels of PA and LS well as a decrease of NA on the next day. Figure 4.2 depicts all three models.

Joint models

Finally, we predicted each of the three components of SWB in joint models that included all sleep variables as predictors and one component of SWB (i.e., PA, NA, and LS) as a dependent variable at a time. The model estimates *b*, *t*-values, degrees of freedom, and *p*-values models can be found in Table 4.3.

When predicting PA simultaneously from five sleep indicators, we only found higher sleep satisfaction to be a statistically significant predictor of increased PA, $b = 0.13$, $t(63.42) = 5.34$, $p < .001$. Similarly, when predicting NA from five sleep indicators, only higher sleep satisfaction significantly predicted lower levels of NA, $b = -0.07$, $t(94.20) = -2.75$, $p = .007$. In other words, people who were more satisfied with their previous night's sleep than on average across the fourteen-day period had higher levels of PA and lower levels of NA on the next day.

As for LS, both previous night's sleep duration and sleep satisfaction were significant predictors of LS on the next day, $b = -0.06$, $t(52.60) = -2.54$, $p = .014$ and $b = 0.23$, $t(86.54) = 4.53$, $p < .001$, respectively. Those who slept shorter than their personal average and those who were more satisfied with their previous night's

Table 4.2

Model Estimates b, t-Values, Degrees of Freedom-and p-Values of the 15 Single Mixed Models Predicting a Component of SWB (PA, NA, and LS) From Self-Reported Sleep Onset Latency, Sleep Duration, Absolute Social Jetlag, Sleep Satisfaction, and Actigraphy-Derived Sleep Efficiency

	PA				NA				LS			
	b	*t*	*df*	*p*	*b*	*t*	*df*	*p*	*b*	*t*	*df*	*p*
Sleep onset latency	0.00	0.44	1150.20	.659	0.00	0.25	1152.47	.799	0.00	0.63	1143.97	.530
Sleep duration	0.02	2.06	54.16	**.045**	-0.01	-0.84	63.24	.403	0.00	-0.12	46.57	.914
Absolute social jetlag	-0.01	-0.45	69.90	.652	0.01	0.70	1223.87	.485	-0.01	-0.23	70.44	.816
Sleep satisfaction	0.14	6.25	58.39	**<.001**	-0.07	-3.00	83.01	**.004**	0.24	4.41	74.51	**<.001**
Sleep efficiency	0.00	0.65	77.95	.515	0.00	0.68	28.72	.501	0.00	-0.18	59.98	.859

Note. SWB = Subjective well-being; PA = Positive Affect; NA = Negative Affect; LS = Life Satisfaction; b = unstandardised model estimates; df = degrees of freedom. Significant findings at $p < .05$ are highlighted in bold.

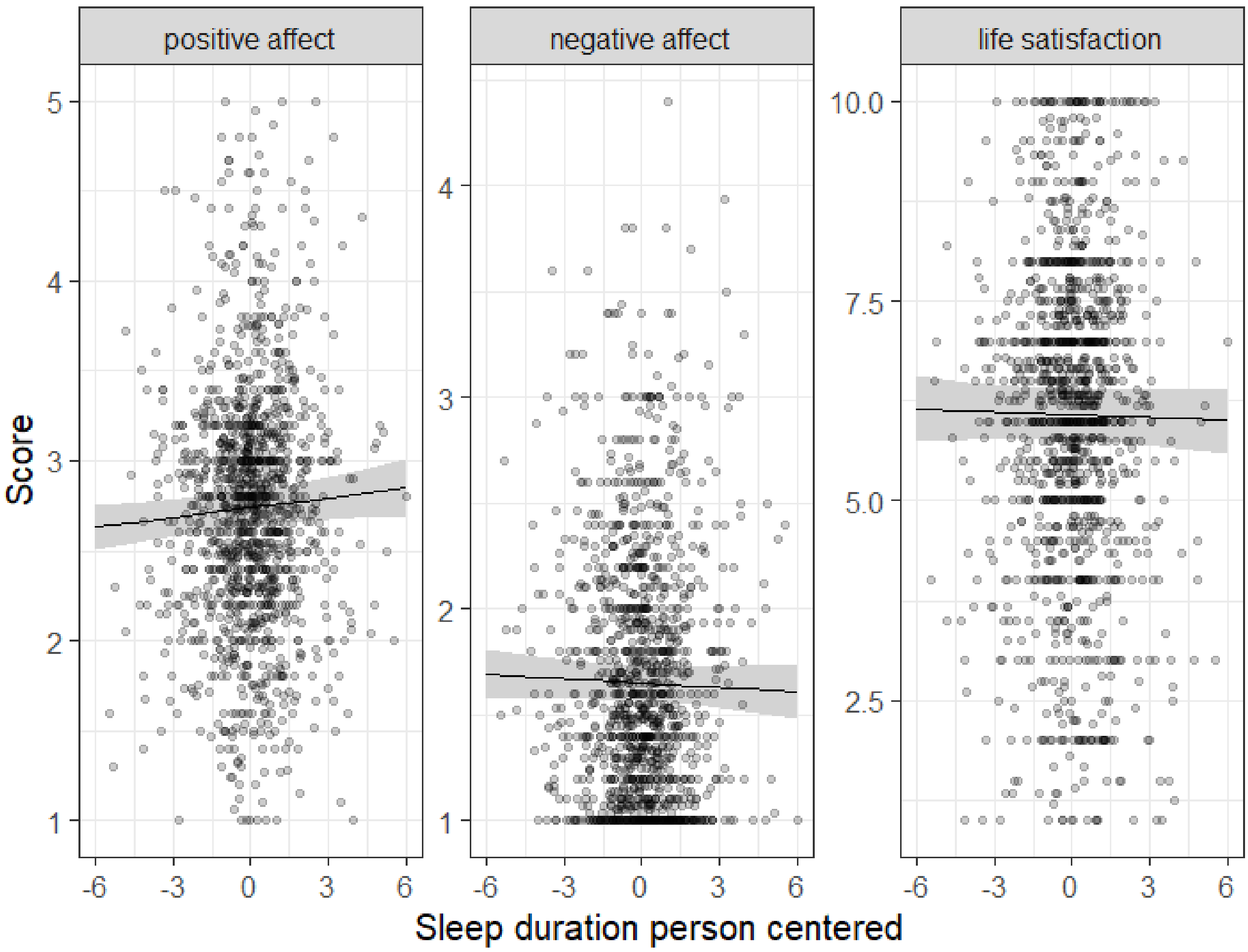

Figure 4.1: Graphs depicting the mixed models predicting the next day's positive affect, negative affect, and life satisfaction from the last night's sleep duration. The x-axis depicts person-centred sleep duration in hours. A negative score indicates a shorter sleep duration than average, whereas a positive score indicates a longer than average sleep duration.

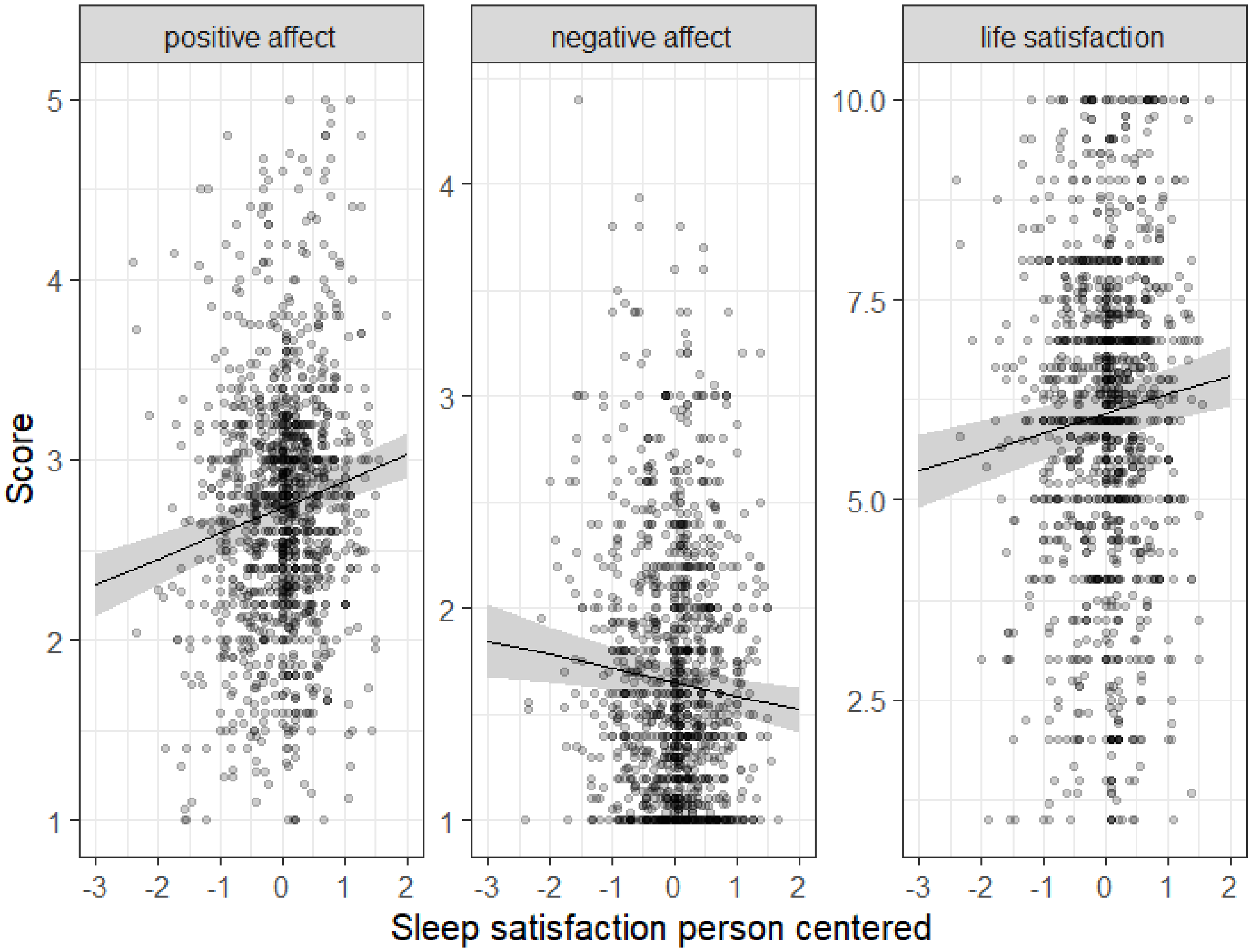

Figure 4.2: Graphs depicting the mixed models predicting the next day's positive affect, negative affect, and life satisfaction from the last night's sleep satisfaction. The x-axis depicts person-centred sleep satisfaction measured on a four-point-scale. A negative score indicates worse sleep satisfaction than average, a positive score better than average sleep satisfaction.

Table 4.3

Model Estimates b, t-Values, Degrees of Freedom-and p-Values of the Three Joint Models Predicting a Component of SWB (i.e., PA, NA, and LS) From Self-Reported Sleep Onset Latency, Sleep Duration, Absolute Social Jetlag, Sleep Satisfaction, and Actigraphy-Derived Sleep Efficiency

	PA				NA				LS			
	b	*t*	*df*	*p*	*b*	*t*	*df*	*p*	*b*	*t*	*df*	*p*
Intercept	2.74	47.88	142.6	**<.001**	1.63	34.45	131.62	**<.001**	6.03	33.86	123.89	**<.001**
Sleep onset latency	0.00	1.84	733.64	.067	0.00	0.07	657.01	.941	0.00	1.26	652.81	.207
Sleep duration	0.00	-0.23	74.07	.816	0.00	0.33	64.33	.739	-0.06	-2.54	52.66	**.014**
Absolute social jetlag	-0.01	-0.67	920.82	.503	0.02	1.01	66.38	.314	-0.02	-0.34	79.13	.733
Sleep satisfaction	0.13	5.34	63.42	**<.001**	-0.07	-2.75	94.20	**.007**	0.23	4.53	86.54	**<.001**
Sleep efficiency	0.00	-0.38	962.63	.705	0.00	1.06	27.51	.298	0.00	-0.57	52.13	.571

Note. SWB = Subjective well-being; PA = Positive Affect; NA = Negative affect; LS = Life Satisfaction; *b* = unstandardised model estimates; *df* = degrees of freedom. Significant findings at $p < .05$ are highlighted in bold.

sleep, both compared to their 14-day average, were more satisfied with their lives the next day. We only found the effect of shorter sleep duration on life satisfaction in the joint, but not single model.

4.4 Discussion

Our study provides evidence that higher satisfaction with the previous night's sleep than during the 14-day average predicts higher PA, lower NA, and higher LS on the following day. The direction of the relationship aligns with previous studies and the hypotheses proposed in our pre-registration (Ong et al., 2017; Shen et al., 2018). Longer than average sleep duration was associated with higher levels of PA the next day, but with no other components of SWB. Sleep onset latency, social jetlag, and sleep efficiency did not significantly predict any component of SWB. In the joint models, only sleep satisfaction predicted higher PA and lower NA, whereas both greater sleep satisfaction and shorter sleep duration significantly predicted LS the next day.

Our findings indicate that the subjective perception of how one has slept is the best indicator of SWB and is more important than objectively measured sleep indicators such as sleep efficiency. This aligns with previous research that showed that only self-reported and not objective measures of sleep were able to (better) predict next day's fatigue or pain (C. Russell, Wearden, Fairclough, Emsley, & Kyle, 2016; Tang, Goodchild, Sanborn, Howard, & Salkovskis, 2012). A study by Kööts-Ausmees and colleagues (2016) found that it is the component of satisfaction or evaluation that is common to subjective health and well-being ratings. This seems to be also true for the evaluative component of sleep—for example, sleep satisfaction—as it was related to all three components of SWB in our study.

We also found that longer than average sleep duration was associated with higher PA the next day. Wrzus et al. (2014) found that in adults over 20 years of age, both shorter and longer than average sleep duration were associated with worse affective well-being the next day, whereas in adolescents, longer sleep duration did not influence next day's affective well-being; indicating that longer sleep duration is at least not harmful in adolescents. The National Sleep Foundation recommends seven to nine hours of sleep per night for young adults (Hirshkowitz et al., 2015). Our participants slept on average 7.41 ($SD = 1.01$) hours per night, and therefore sleeping longer than average still falls within the recommended range in the current study.

In the joint models, only sleep satisfaction predicted PA and NA, whereas both sleep satisfaction and sleep duration were significant predictors of next day's LS. Only when adjusting for the values of all other covariates (i.e., holding them constant), we find that shorter sleep duration is associated with higher life satisfaction. In other words, if one's sleep satisfaction is the same on two days, then sleeping less is additionally associated with higher life satisfaction. It seems counterintuitive that shorter sleep duration is associated with greater satisfaction of life on the next day as it has been linked to lower SWB in previous research (see for example Wrzus et al., 2014). We can only speculate that those who sleep shorter than their personal average, but still are as satisfied with their sleep as before, might have more time to achieve their goals on the next day, and thus be more satisfied with their lives.

4.4.1 Strengths, Limitations, Future Research, and Conclusions

We used an experience sampling approach which allowed us to capture more true life experiences in a natural setting (Scollon, Prieto, & Diener, 2003). This is different from many previous studies that primarily used cross-sectional designs to examine the relationships between sleep and SWB (see for example Dagys et al., 2012; Diaz-Morales & Escribano, 2015; Gaina et al., 2005; Rossa et al., 2014). There are individual differences in sleep indicators, for example humans differ in the amount of sleep they require per day (van Dongen et al., 2005). By assessing multiple observations in the same participants over a period of two weeks, we were able to examine if and to what extent deviations from one's personal average levels are related with SWB.

Due to the design of the study, participants had only 20 minutes to respond to the momentary surveys assessing SWB. This is in line with other experience sampling studies that typically use an arguably arbitrary cut-off of below 30 minutes to avoid memory biases and the use of heuristics (Scollon et al., 2003). The cut-off point might have lowered the response rate in momentary prompts. Even though we compensated our participants with up to £35, this still might not have been enough to achieve a higher compliance rate. However, as the final analysis is based on over 1,200 observations for each statistical model, we feel that some confidence in our results is justified.

Another limitation of our study is that we only used a homogenous sample of 18-22 years old university students, of whom a vast majority owns a smartphone, which is why our results cannot be generalised to the general public. Therefore, future studies could investigate how sleep influences SWB on the next day using participants of all ages and from different sociodemographic groups. It would also be interesting to study persons who experience severe daily social jetlag and examine how it affects their next day's SWB. This desynchrony between biological and social clocks might be especially relevant for people who work in shifts since social jetlag is a smaller version of shift work (Roenneberg et al., 2012).

Overall, our study has provided valuable insights that the evaluative component of sleep—satisfaction with last night's sleep—is the factor most related to the SWB on the following day. Sleep satisfaction, but not actigraph-measured sleep efficiency, was a significant predictor of SWB in all models. This highlights the importance of studying both how sleep is objectively measured and how humans perceive their sleep, as objective and subjective measures of sleep seem to work differently in predicting SWB. Our study implies that sleep interventions targeting sleep satisfaction may prove effective in improving young adults' SWB and, thus, also student mental health. Using experience sampling methodology allowed us to understand better the relationship between sleep and SWB in a sample of undergraduate students; future research should investigate whether these results can be generalised to other populations and settings of interest.

Chapter 5

Discussion and Conclusion

The general focus of this thesis was to better understand changes in sleep timing, factors associated with sleep timing, and its influence on the three components of subjective well-being.

More specifically, the aims of this PhD thesis were to explore the intraindividual variability and temporal stability of sleep timing, how personality influences sleep timing, and how sleep timing and other dimensions of sleep are related to subjective well-being. I explored sleep timing on multiple levels of analysis and also related multiple dimensions of sleep to positive affect, negative affect, and life satisfaction.

In this final chapter of my thesis, I will summarise the findings of the studies comprising the thesis and answer the research questions I posed in the introductory chapter of my thesis (Chapter 1). I will then move on to the theoretical, methodological, and practical implications of my research and discuss ideas for future studies.

5.1 Overview of the Findings

In the following section, I will present an overview of my findings—addressing the questions posed at the start of my thesis.

5.1.1 Chapter 2

The two studies of Chapter 2 aimed to answer three research questions which were on the intraindividual variability (RQ1), ecological validity (RQ2), and long-term stability (RQ3) of mid-sleep. To answer the research questions, I used data from an experience sampling study of students at the University of Warwick (RQ1 and RQ2) as well as data from the Estonian Biobank (RQ3).

RQ1: What is the ratio of the daily intra- and interindividual variability of midpoint of sleep over a period of two weeks when taking into account the effect of free and workdays?

Participants were asked to keep a sleep diary for the course of two weeks using a smartphone application. Therefore, we could study our participants' sleep times in a natural setting. We used the bed and wake-up times of the sleep diaries to calculate daily mid-sleep scores for every participant.

In an intercept-only model that predicted mid-sleep, we found that roughly 50% of the variance in daily mid-sleep scores was attributed to intraindividual variability. This indicated that mid-sleep scores differed as much within as between participants. When we included workdays into the model, the intraindividual variability was 0.71 the size of the interindividual variability, hence much smaller. Thus, the same participants tend to have similar mid-sleep times during workdays and similar mid-sleep times on free days.

Our results are consistent with the results of previous laboratory studies that investigated the intraindividual variability of circadian rhythms in humans (Selmaoui & Touitou, 2003) and non-human animals (see for example Refinetti & Piccione, 2005; Romeijn & Van Someren, 2011; Sharma, 1996; Wassmer & Refinetti, 2019). However, chronotype in a natural setting is not only influenced by circadian rhythms but also sleep pressure and the social component (Roenneberg et al., 2019). Given the similarity of our results, it is possible that other factors influencing chronotype, such as sleep pressure and the social component, do not vary much within the same participants over a short period of time once work and free days are taken into account.

RQ2: How does average daily assessment of midpoint of sleep relate to retrospective and actigraphy-derived assessments?

The MCTQ assesses chronotype through retrospective estimates of the previous four weeks' sleep times separately for free and workdays (Roenneberg et al., 2003). While filling out retrospective questionnaires, participants often engage in memory biases (Shiffman et al., 2008) and thus may not be able to remember their respective behaviours accurately.

To assess whether the retrospective MCTQ accurately reflects actual sleep behaviour, we correlated mid-sleep of both free and workdays with the average biweekly scores from the sleep diaries. We found that the retrospective and average momentary assessments correlated strongly with each other, $r = .73$ for free days and $r = .79$ for workdays (ps $< .001$). However, participants filled in the MCTQ before the experience sampling study started and thus the time windows of the MCTQ and the experience sampling study did not match. This indicates that participants tended to go to bed and wake up at similar times during the 1.5 months period. When we compared the average actigraphy-derived mid-sleep scores with the mid-sleep scores from the sleep diaries (thus the same period of two weeks), we found that mid-sleep on free days correlated at $r = .80$ and on workdays at $r = .97$ ($ps < .001$). The actigraphy-derived scores of mid-sleep were anchored on the bed- and wake-up times from the sleep diaries which might explain the very strong correlations.

Our results indicate that people can estimate quite well at what time they fall asleep and wake up and that their sleep times are relatively similar throughout different periods of times of up to 1.5 months. People's recall of their bedtimes is greatest on workdays. People might have similar bedtimes on workdays (as wake up times are determined by work and school schedules; Roenneberg et al., 2003) whereas bedtimes on free days might be less predictable for the participants themselves.

RQ3: How stable is midpoint of sleep on free and workdays over a period of 0-1 to 5 years when also taking into account the effect of age?

To assess the temporal stability of mid-sleep on free and workdays, we used data from participants of the Estonian biobank who filled in the MCTQ (Roenneberg et al., 2003) twice up to five years apart from each other. The test-retest correlations of mid-sleep on free and workdays were $r = .66$ and $r = .58$ (ps < .001). We then tested how age affected the stability of mid-sleep on free and workdays using a) Asendorpf's (1992) t-transformed coefficients of individual stability and plotting them by age and b) test-retest correlations per age group. Both analyses showed that the stability of mid-sleep of free and workdays was largely affected by age, and that the stability of mid-sleep was the lowest when participants were in the younger and older age groups and the highest when they were in their late 40s to early 50s.

The age-specific changes in the stability of mid-sleep could be explained by the social component that Roenneberg et al. (2019) suggested to add to the two-process model of sleep regulation (Borbély, 1982). As chronotype is also influenced by one's work and social schedules (Roenneberg et al., 2019), it might be that middle-aged participants have stable life circumstances whereas those of younger and older participants are more likely to change. There are social life-cycle effects (e.g., finishing school, finding a job, getting married, settling down, retiring, etc.) that are intertwined with the biological process of aging (Glenn, 2003) and these typically occur with younger and older age.

5.1.2 Chapter 3

The study in Chapter 3 aimed to explore the relationship between the FFM personality traits and chronotype at both the genetic and phenotypic level.

RQ 4: How are all three levels of the FFM personality hierarchy related with chronotype both at the phenotypic and genetic level?

Chronotype has been linked to personality in past research (e.g., Lipnevich et al., 2017). In Chapter 3, we first wanted to investigate how chronotype and the FFM personality traits are related with each other at all three levels of the FFM personality hierarchy (e.g., domains, facets, and items) and which possible mechanisms might explain the relationship. We were also interested in finding out how chronotype and the FFM personality traits are related to each other at a genetic level when using polygenic scores of both FFM personality traits and chronotype.

We found that chronotype and the FFM personality traits were related to each other at all three levels of the FFM personality hierarchy. On the domain level, later chronotype was related to higher levels of Openness and lower levels of Conscientiousness when controlling for sociodemographic variables and season. On a facet level, more straightforward (A2) and excitement-seeking (E5), yet less self-disciplined (C5) people were more likely to have later chronotypes. The correlation between chronotype and the Polypersonality score consisting of 23 weighted items was $r = .28$ ($p < .001$). We also suggested two possible pathways of how personality might influence chronotype. People either engage in specific behaviours that make them go to bed earlier or later or they actively decide at what time they go to bed due to specific goals they want to achieve. Other possibilities include chronotype influencing the FFM personality traits or that the FFM personality traits and chronotype mutually influencing each other.

Chronotype and the FFM personality traits may also be related to each other at a genetic level as both constructs have been associated with similar outcomes such as health and mortality in past research (H. S. Friedman & Kern, 2014; Partonen, 2015). We associated the polygenic scores of personality with self-reported chronotype and the polygenic score of chronotype with personality domains, facets, and the item-level Polypersonality score. We found that personality PGSs were not able to predict chronotype but that the chronotype PGS predicted the Polypersonality score. Thus, there might be a polygenic overlap between the FFM personality traits and chronotype (Cheesman et al., 2019; Turkheimer et al., 2014).

Out of the FFM domains, only the Neuroticism PGS predicted its corresponding phenotypic personality domain and facets. This indicates that the PGSs for Extraversion, Openness, Agreeableness, and Conscientiousness do not have sufficient predictive validity yet. Thus, it is not surprising that they also could not predict another trait, i.e., chronotype. The chronotype PGS showed good predictive validity even though it was trained on morningness-eveningness (Jones et al., 2019). Interestingly, the PGS for chronotype was only able to predict the Polypersonality score and not personality domains or facets, indicating that personality items seem to best predict the association between personality and chronotype. Items might be related the most to specific behaviours of when to go to and get out of bed.

5.1.3 Chapter 4

Chapter 4's aim was to examine the relationship between sleep and the three components of subjective well-being (positive affect, negative affect, and life satisfaction).

RQ5: How are sleep timing as well as other sleep parameters such as sleep onset latency, sleep duration, sleep satisfaction, and sleep efficiency related to next day's subjective well-being within participants?

Studies have shown that people differ between each other in their sleep parameters (van Dongen et al., 2005), hence people on average go to bed and wake up at different times, sleep for a different amount of time, or have a different chronotype. Furthermore, the same people also differ within their sleep parameters on a day-to-day basis (Buysse et al., 2009). It is important to study within-person processes (Curran & Bauer, 2011) as results that are true for between-person processes cannot necessarily be applied to changes within a person. For example, higher levels of physical exercise decrease the likelihood of having a heart attack (between person-effect) whereas heavy physical exertion can also trigger a heart attack (within-person effect; see for example Curfman, 1993; Mittleman et al., 1993). Therefore, daily differences in one's sleep parameters might also influence the three components of subjective well-being.

Subjective well-being has been linked to several sleep indicators in past research (see for example Adan et al., 2012; Diaz-Morales & Escribano, 2015; Ong et al., 2017; Wrzus et al., 2014). In the current study, we wanted to investigate the association between sleep and subjective well-being within participants as most previous studies have investigated it across participants. We therefore explored how daily deviances from one's 14-day average sleep onset latency, sleep duration, sleep satisfaction, and sleep efficiency and daily deviances from one's mid-sleep on free days (a daily measure of social jetlag; MCTQ; Roenneberg et al., 2003) were related to all three components of next day's subjective well-being.

We found that it was the subjective component of sleep, i.e., sleep satisfaction that was consistently related to all three components of subjective well-being. Those who reported higher than average sleep satisfaction had higher positive affect, lower negative affect, and higher life satisfaction on the next day. This was true for both the single and joint models (i.e., predicting the three components of subjective well-being from one sleep indicator at a time or all five of them together). We found mixed results regarding the effect of sleep duration on subjective well-being. In the single models, longer than average sleep duration was related to higher positive affect on the next day. Sleep duration was not related to negative affect or life satisfaction. In the joint models, shorter than average sleep duration together with higher-than-average sleep satisfaction was related to higher life satisfaction on the next day. The other sleep indicators did not significantly predict any component of subjective well-being. Therefore, one's subjective perception of how one has slept is a better indicator of subjective well-being than for example objectively measured sleep efficiency. Subjective sleep satisfaction not only seems to be determined what happens when we sleep but also what happens after sleeping and therefore includes an evaluative component (Ramlee et al., 2017). Thus, sleep satisfaction might also be intertwined with current subjective well-being.

The results for sleep duration are contrary to what we expected in our pre-registration as we predicted shorter or longer sleep duration to be associated with lower positive affect and lower life satisfaction. However, our participants on average slept 7.41 ($SD = 1.01$) hours per night which means that most of our participants followed the recommendation by the National Sleep Foundation of 7-9 hours per night for young adults (Hirshkowitz et al., 2015). Therefore, shorter and longer sleep duration may have still fallen within the sleep recommendations. In the joint model, we found that only shorter sleep duration in combination with higher sleep satisfaction was related to next day's life satisfaction. Therefore, only if one's sleep satisfaction is the same on two days, then sleeping less is additionally associated with higher life satisfaction. It could be that in this specific situation, participants feel refreshed, but also have more time to achieve their goals on the day when waking up.

5.2 Theoretical, Methodological and Practical Implications of the Findings

This section starts with the theoretical and methodological implications of our research and ends with practical implications of the studies.

5.2.1 Theoretical Implications

Adding personality to the two/three-process model of sleep regulation

In the laboratory, the duration and timing of sleep are influenced by Process S and Process C (Borbély, 1982; Borbély et al., 2016). However, under normal circumstances, the duration and timing of sleep is also entrained by *zeitgebers*, such as natural (Roenneberg et al., 2007) and artificial light (Vetter et al., 2011), as well as social and professional demands (Abbott et al., 2017; Leonhard & Randler, 2009). With the invention of alarm clocks and artificial light, people can nowadays decide themselves more easily at what time they want to go to bed and wake up (Czeisler & Buxton, 2017) which means that they do not necessarily have to follow their biological rhythms (Roenneberg et al., 2019). Roenneberg et al. (2019) recently suggested adding a social component to the two-process model of sleep regulation. The social component includes any aspect that influences timing of sleep such as societal and work schedules but also human behaviour. As behaviour is an implicit component of personality (Asendorpf & Rauthmann, 2020; Johnson, 1997), it could be that personality influences the behaviours associated with both bedtime and wake-up time. Our findings indicate that the FFM personality traits are related to chronotype at all three levels of the FFM personality hierarchy (Chapter 3) suggesting that personality does play a big role in chronotype.

Examples of human behaviour that influence chronotype are watching a late TV show, reading a thrilling book, or engaging in social interaction or events (Roenneberg et al., 2019). Some of these activities, even though not at a specific time, have also been linked to the same FFM personality domains and facets (see for example Dumfart & Neubauer, 2016; Rohrer & Lucas, 2018; Trapp & Ziegler, 2019). However, we assume that these activities often happen during one's free time, and therefore also on evenings. In Chapter 3, we suggested two pathways that aligned with our results of how personality might influence one's bedtimes, either through shaping people's preferences for certain activities or active decisions people make regarding their sleep. These pathways assume that people's behaviours that determine sleep times are also influenced by personality.

In the three-process model of sleep regulation that Roenneberg et al. (2019) proposed, the behavioural aspect of the social component could be expanded by personality. In particular, within the social component, there could be a direct path between the FFM personality traits and behaviour that influences bed- and wake-up times. For example, our research has shown that people high in Openness are more likely to be late chronotypes. They also often engage in activities that happen in the evening, such as going to concerts, restaurants and bars (Mehl et al., 2006; Nusbaum & Silvia, 2010). Thus, their bedtimes might be influenced by these specific behaviours they enjoy and might make them go to bed later than their biological clocks would want them to go.

5.2.2 Methodological Implications

Using the MSF from the MCTQ (Roenneberg et al., 2003) or MSF corrected for sleep debt from the μMCTQ (Ghotbi et al., 2019)

Mid-sleep on free days corrected for sleep debt (the marker of chronotype proposed in the MCTQ) can only be calculated when participants do not use an alarm clock on free days (Roenneberg et al., 2003). This leads to the exclusion of many participants which a) results in the loss of valuable data and b) wastes participants' time, thus reducing test efficiency (Moosbrugger & Kelava, 2012).

These were some of the reasons why we did not adjust MSF for sleep debt in the main analysis of the second study of Chapter 2. However, due to the request of an anonymous reviewer, we also ran the analyses for MSF_{sc} and found similar results (see Appendix A). MSF and MSF_{sc} also were highly correlated with each other (*r*s = .95 at T1 and T2, *ps* < .001), indicating that the two constructs might not be as different as originally proposed. Therefore, one might use MSF and not MSF_{sc} and not lose the valuable data of many participants despite gaining similar results.

Another option would be to use the recently developed shortened version of the MCTQ- the μMCTQ- which still uses a version of mid-sleep corrected for sleep debt without the exclusion of participants who use an alarm clock (Ghotbi et al., 2019). In the questionnaire, participants are already asked about their sleeping patterns of free days when no alarm clock is used. The μMCTQ also uses fewer questions and therefore it takes less time for participants to fill it out. Using the μMCTQ would enable the use of data from all participants who filled out the questionnaire correctly. However, MSF corrected for sleep debt from the μMCTQ correlated at r = .43 ($p < .05$) with DLMO which is lower than the correlation between MSF from the MCTQ and DLMO ($r = .71$; Kantermann & Burgess, 2017). Therefore, it might be best to use MSF instead of MSF_{sc}.

MSF_{sc} cannot be used in all circumstances as it is not defined as a daily score (Kühnle, 2006). Thus, it is important to evaluate before the beginning of data collection which measure to use, especially as the μMCTQ only provides a measure of MSF_{sc} and not MSF (Ghotbi et al., 2019).

5.2.3 Practical Implications

More flexible work schedules

In Study 2 of Chapter 2, we showed that both mid-sleep on free and workdays are relatively stable when participants were tested twice during a period of up to five years. Research has shown that when people live against their biological clocks, they experience social jetlag which can lead to worse psychological well-being (Wittmann et al., 2006). In Study 2 of Chapter 2, we also showed that the stability of mid-sleep is affected by age, so the temporal stability of mid-sleep is the lowest in younger and older participants and the highest in middle-aged participants. As age is also related to different social life-cycle effects, i.e., life circumstances (Roenneberg et al., 2019), it might be that the change in stability of mid-sleep is mostly related to the stability of life circumstances. Therefore, life circumstances might influence one's bed and wake-up times, and people might be less likely to follow their biological clock.

Many life circumstances that have an effect on sleep times such as having children and living together with a partner (Leonhard & Randler, 2009) cannot really be changed without any consequences. However, as we know that chronotype is also influenced by work schedules (Roenneberg et al., 2019), flexible work hours would allow people to live in greater alignment with their biological clocks. For example, late chronotypes can wake up later for work without compensating for sleep debt on free days (Roenneberg et al., 2003). Weekend catch-up sleep does not fully compensate for sleep debt (Leger, Richard, Collin, Sauvet, & Faraut, 2020) and sleep deprivation studies have also shown that not all lost sleep can be recovered immediately (Dijk & Lazar, 2012). Therefore, it is important that participants do not accumulate detrimental amounts of social jetlag. When adults have school-aged children, their wake-up times are also influenced by school times. Both parents and adolescents could benefit from delayed school times as adolescents typically exhibit the latest chronotypes (Adan et al., 2012) and often feel tired in the morning (Gariépy, Janssen, Sentenac, & Elgar, 2017). More flexible work schedules and later school times might improve the psychological well-being of both adults and adolescents.

The results of Chapter 2's Study 2 showed that people's mid-sleep might be dependent on life circumstances, which means that people's mid-sleep scores could also change if people were given the opportunity to choose their bedtimes according to their biological clocks, for example when having more flexible work schedules.

Interventions focusing on C5- Self-discipline

When it is not possible to alter outside circumstances, it might be possible to alter one of the lower-level personality traits that is related to sleep timing, or at least its associated behaviours. We showed that C5- Self-discipline is negatively related to chronotype, so that more self-disciplined people are more likely to be earlier chronotypes. Self-discipline refers to the ability to begin tasks and carry them out until completion despite boredom and other distractors (Costa & McCrae, 1992). Self-discipline has been used synonymously with self-control (Duckworth, 2011). Self-control interventions have proven to be quite successful in enhancing one's levels of self-control (Muraven, 2010). Therefore, it might be possible for late chronotypes to shift to an earlier chronotype in a more intentional way which may improve their health and even lengthen their lives (Partonen, 2015).

People's circadian rhythms are heavily influenced by light (Duffy, Kronauer, & Czeisler, 1996). Hence, if later chronotypes create a habit of turning off earlier their artificial lights, it might also result in a shift of their circadian rhythms such as melatonin and body temperature. They then might also feel tired earlier and be able to fall asleep.

Improving sleep satisfaction/quality

As already explained in Chapter 4, the terms sleep quality and sleep satisfaction are often used synonymously (Harvey et al., 2008). In Chapter 4, we showed that it was the evaluative component of sleep, i.e., sleep satisfaction that was consistently related to all three components of next day's subjective well-being. Those who slept better than their personal two-week average, showed higher positive affect, lower negative affect, and higher life satisfaction on the next day. Both experience sampling and longitudinal studies report that it is primarily sleep that is influencing components of subjective well-being (Kalak et al., 2014; Simor et al., 2015; Totterdell et al., 1994; Triantafillou et al., 2019). Therefore, improving one's sleep satisfaction might lead to an overall better subjective well-being. However, as Ramlee et al. (2017) argue, improving mood and functioning throughout the day might also improve people's evaluation of their sleep quality. It might also be that sleep satisfaction is just another facet of subjective well-being or a subfacet of general life satisfaction.

Several meta-analyses have shown that it is possible to improve sleep quality in insomnia, for example with cognitive behavioural therapy (van Straten et al., 2018), exercise (Lederman et al., 2019), or music (Feng et al., 2018). A recent study by Espie and colleagues (2019) showed that digital cognitive behavioural therapy can also improve psychological well-being, thus indicating that there might be a path between sleep quality and (psychological) well-being. Therefore, it could also well be that improving sleep quality and thus altering the evaluation of one's sleep would enhance one's subjective well-being even within a non-clinical population.

5.3 Suggestions for Future Research

In the empirical chapters of my research, I made several suggestions for future research. I will summarise those briefly but also include a few additional suggestions.

5.3.1 Chapter 2—Intraindividual Variability and Temporal Stability of Mid-Sleep on Free and Workdays

In Study 1, we only investigated intraindividual variability of mid-sleep during a period of two weeks in university students. To generalise our findings, one could also investigate its variability over longer periods of time using representative samples. Our participants were primarily 18-22-year-olds, who typically exhibit a later chronotype (Adan et al., 2012) and thus a wider age range could enhance the generalisability of our results. It would also be interesting to study how early and late chronotypes differ in the variability of mid-sleep. Kühnle (2006) reported that the correlation between MSF from the MCTQ and MSF from a six-week-long sleep log was much lower in early and late chronotypes than in "normal" chronotypes, indicating that the variability of mid-sleep might also be dependent on chronotype.

As we used secondary data analysis for Study 2, we did not have an influence on the design of the study. We were able to compare the test-retest correlations of multiple time intervals at once, but we did not use a proper longitudinal approach that would allow examination of the intraindividual stability of mid-sleep in the same individuals across the same periods of time. Future studies that test the same participants multiple times over multiple years are necessary to further investigate the temporal stability of mid-sleep. As we proposed that life circumstances might be the reason why temporal stability of mid-sleep is the greatest in middle-aged participants, it would be interesting to investigate which precise life circumstances influence the temporal stability of mid-sleep.

5.3.2 Chapter 3—FFM Personality Traits and Chronotype

In Chapter 3, we only studied participants who lived in Estonia. Estonia is characterised by short amounts of daylight in winter and many hours of daylight in summer which is why we adjusted our results for season. As light is a major *zeitgeber* to circadian rhythms (Aschoff, 1965), our findings might have differed in other countries that vary less in daylight hours across seasons. It could be that the influence of personality on chronotype is dependent on the amount of daylight. Future studies with large scale samples should focus on the generalisability of the findings around the globe in places with different latitudes.

To avoid overfitting, we used cross-validation when coming up with the item-level Polypersonality score. Our model identified 23 items from the NEO-PI-3 which were given specific weights and summed up to as Polypersonality score. We used this approach since no studies had investigated the relationship between chronotype as assessed with the MCTQ and the 240-item NEO-PI-3 before. It would be interesting to see whether the Polypersonality score we identified also correlates with MSF_{sc} in other datasets. The items we presented in the main analysis were combined self-and informant ratings. We identified a different number of items when we calculated the Polypersonality score for self- and informant reports separately, which also needs to be accounted for when validating our study.

To better understand the causality between the FFM personality traits and chronotype, longitudinal studies are needed as they can disentangle the temporal order of events. If it is the FFM personality traits that influences one's sleep timings, it would be interesting to further explore the two pathways we suggested of how personality might influence sleep timings. One could examine how sleep timings are influenced by a person's personality, either by engaging in specific activities that are related to personality or active decisions people make at what time they go to bed and wake up. Future research could explore if and how people consciously decide at what time they go to bed and wake up, and to what extent these decisions can actually change circadian rhythms.

In our study, we did not find that the personality PGSs influenced phenotypic chronotype. However, the PGSs of Extraversion, Openness, Agreeableness, and Conscientiousness did not show predictive validity which might explain why they also were not able to predict phenotypic chronotype. Larger GWASs are necessary to identify more SNPs associated with personality domains and facets so that PGSs with better predictive validity can be calculated. This might lead to a refinement of the genetic personality-chronotype-relationship.

5.3.3 Chapter 4—The Impact of Sleep on Next Day's Subjective Well-Being

In Chapter 4, our participants in the experience sampling study were university students from the University of Warwick. University students are a homogenous group who are similar in their age and socioeconomic status. Therefore, our results are not generalisable to the general public. Future studies could use a similar methodology but with participants of all ages and different sociodemographic variables to identify whether sleep satisfaction also has the biggest impact on next day's subjective well-being. If our results are generalisable to the general public, then interventions for enhancing sleep satisfaction to improve subjective well-being could be especially promising.

Our results showed that daily social jetlag did not influence any of the three components of next day's subjective well-being. However, our participants experienced very little social jetlag as their biological and social clocks on average differed by less than one hour (Roenneberg et al., 2012). Their social jetlag may have been insufficient to study its impact on subjective well-being. Therefore, an effect of social jetlag miight only be detectable in people who experience detrimental amounts of social jetlag or work in shifts. It would be interesting to see how larger than average daily social jetlag affects subjective well-being on the next day in these specific populations. This way we could test whether the amount of daily social jetlag influences subjective well-being. In our study, we did not correct social jetlag for sleep debt using the formula that Jankowski (2017) proposed. However, it seems like social jetlag cannot be corrected for sleep debt as a daily score because daily mid-sleep on free days can also not be corrected for it (Kühnle, 2006). Future research can investigate how social jetlag corrected for sleep debt influences subjective well-being, even if a cross-sectional design has to be applied.

5.4 Conclusion

In this thesis, I examined how timings of sleep are related with age and personality, and how daily deviations from sleep timings and other indicators of sleep affect next day's subjective well-being. To answer my research questions, I used cross-sectional, longitudinal, and experience sampling datasets. I also examined timing of sleep on multiple levels of analysis (i.e., self-report, behavioural, and genetic) and related subjective well-being to multiple dimensions of sleep.

We showed that mid-sleep varies less within than between participants when the effect of free and workdays is taken into account, indicating that participants' sleep times are different on free and workdays, but that on free and workdays they are quite similar to another. We also demonstrated that the temporal stability of mid-sleep is largely affected by age, so that middle-aged participants show the highest test-retest correlations. Future studies will need to investigate how and which life circumstances influence the stability of mid-sleep. We showed that personality and chronotype were related at all three levels of the personality hierarchy and that personality and chronotype seem to share underlying genetic mechanisms. We also found that sleep satisfaction, i.e., the evaluative component of sleep, was most consistently related to next day's subjective well-being.

Our findings offer a wide range of practical implications which which will ideally improve the general population's subjective well-being, for instance, by enhancing sleep satisfaction or self-discipline. I have suggested various avenues for future studies that can build upon and refine the results of my thesis. Overall, my research has provided a better understanding of the change in sleep timings, the relationship between sleep timings and personality, and how sleep timings and other indicators of sleep are related to subjective well-being.

Appendix A

Correcting Mid-Sleep on Free Days for Sleep Debt (Chapter 2, Study 2)

A.1 Introduction and Method

As chronotype is often operationalised as mid-sleep on free days corrected for sleep debt (MSF_{sc}; Roenneberg, 2015; Roenneberg et al., 2003), we wanted to ensure that our analyses were not influenced by the decision to only investigate mid-sleep on free days (MSF). MSF_{sc} can only be calculated if participants do not use an alarm clock on weekends. If the sleep duration on free days is smaller than or equal the sleep duration on workdays, MSF does not need to be corrected. When the sleep duration on free days is greater than the sleep duration on workdays, it is calculated as such:

$$MSF_{\mathrm{sc}} = MSF - \frac{(SD_{free} - SD_{week})}{2}$$

where SD_{free} is equal sleep duration on free days and SD_{week} is equal sleep duration on workdays.

We had to exclude 118 participants because they had used an alarm clock on free days at either the first or second time of assessment. Therefore, our final sample consisted of 563 participants. As the exclusion of participants might have impacted our results, we re-ran the analyses for both MSF and MSF_{sc}. The mean age of the participants at T1 was 49.57 (SD = 15.51). Around half of the participants identified as female (272; 48.31%). At T1, 58 (10.30%) participants had basic education, 309 (54.88%) had completed secondary education/secondary vocational education, and 196 (34.81%) had higher education.

A.2 Results

A.2.1 Descriptive Statistics

Across all participants, the average MSF was 3.71 (SD = 1.18) at T1 and 3.65 (SD = 1.19) at T2. The scores did not significantly differ from each other, $t(562) = 1.44$, $p = .150$. The MSF_{sc} score at T1 was 3.39 (SD = 1.02) and 3.38 (SD = 1.08) at T2, $t(562) = 0.28$, $p = .780$. The correlation between MSF and MSF_{sc} at both T1 and T2 was $r = .95$ ($p < .001$), MSF and MSF_{sc} differed from each other significantly at both T1, $t(562) = 19.96$, $p < .001$ and T2, $t(562) = 18.12$, $p < .001$.

A.2.2 Test-retest Reliabilities of Mid-Sleep Scores for the Groups with Different Retest Intervals

The test-retest correlations for this sample were $r = .67$ for MSF and $r = .59$ for MSF_{sc}. All correlations significant at $p < .001$. The test-retest correlations for groups with different test intervals ranging from 0-1 to 5 years of MSF and MSF_{sc} are depicted in Figure A.1. In general terms, the stability of the two variables remained quite high over the course of the years. The overall highest test-retest correlations were found for MSF which ranged from $r = .64$ (2 years) to $r = .74$ (0-1 year) which were slightly higher than the test-retest correlations of MSF_{sc} with rs ranging from .57 (2 years) to $r = .64$ (0-1 and 3 years). However, the test-retest correlations for MSF and MSF_{sc} according to the retest interval did not differ from each other significantly at $p < .05$.

A.2.3 Individual and Group-Level Stability of Mid-Sleep Across the Life Span

Next, we examined how the stability coefficients of MSF and MSF_{sc} depend on age. Figure A.2 and Figure A.3 depict age at T1 on the x-axis and Asendorpf's 1992 t-transformed coefficients of individual stability of MSF (Figure A.2) and MSF_{sc} (Figure A.3) on the y-axis. A t-transformed coefficient of individual stability of 3.8 corresponds to an individual stability coefficient of 1 and a t-transformed coefficient of 2.6 to a coefficient of 0.99. The individual stability of both MSF and MSF_{sc} increases from young adulthood to early 50s and then starts to decline again from mid-50s onwards. We added a quadratic fit to both models which explained 5.47 (equation: $y = -0.001x^2 + 0.094x - 0.740$) and 5.32 (equation: $y = -0.001x^2 + 0.097x - 0.945$) percent of the variance in individual stability. Adding the quadratic terms to both models explained about three percent more of the variance.

To further elaborate on how the rank-order stability of MSF and MSF_{sc} is influenced by age, we divided participants into six age categories at T1: 18-25 (n = 47), 26-35 (n = 76), 36-45 (n = 110), 46-55 (n = 108), 56 to 65 (n = 112), and 66-87 (n = 110). We then calculated test-retest correlations for MSF and MSF_{sc} for each group. Figure A.4 illustrates these test-retest correlations by age group. The rank-order

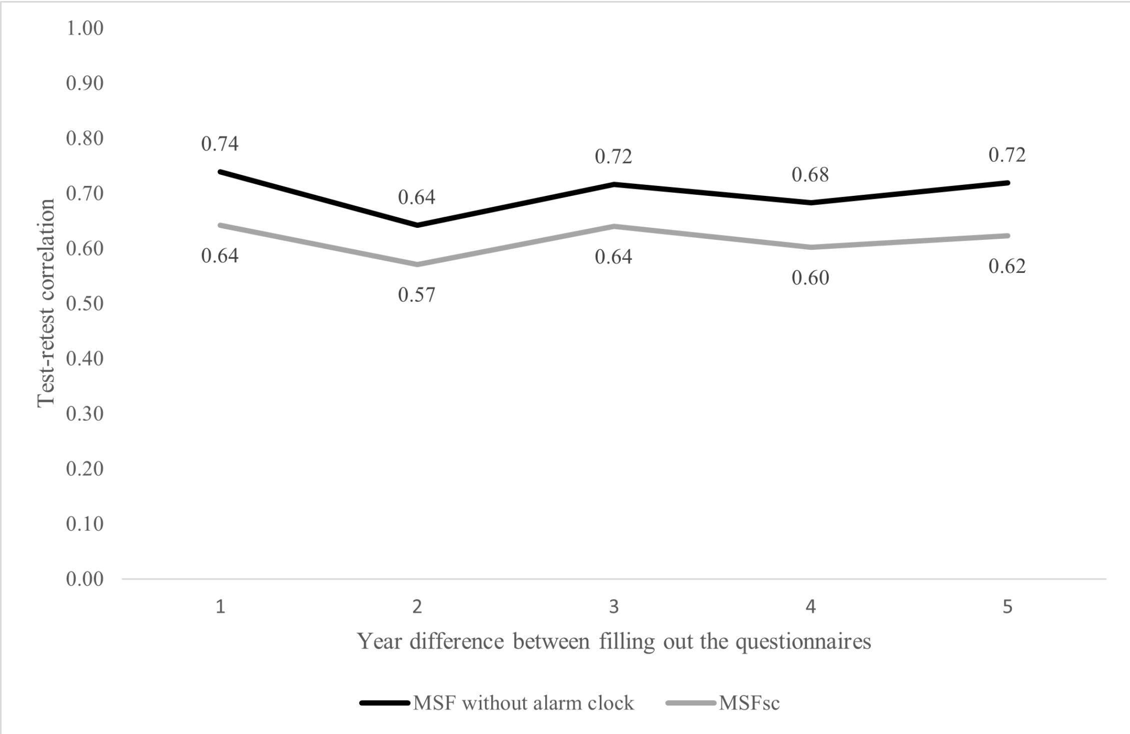

Figure A.1: Test-retest correlations of MSF (mid-sleep on free days) and MSF_{sc} (mid-sleep on free days corrected for sleep debt) according to the time difference between the two measurements.

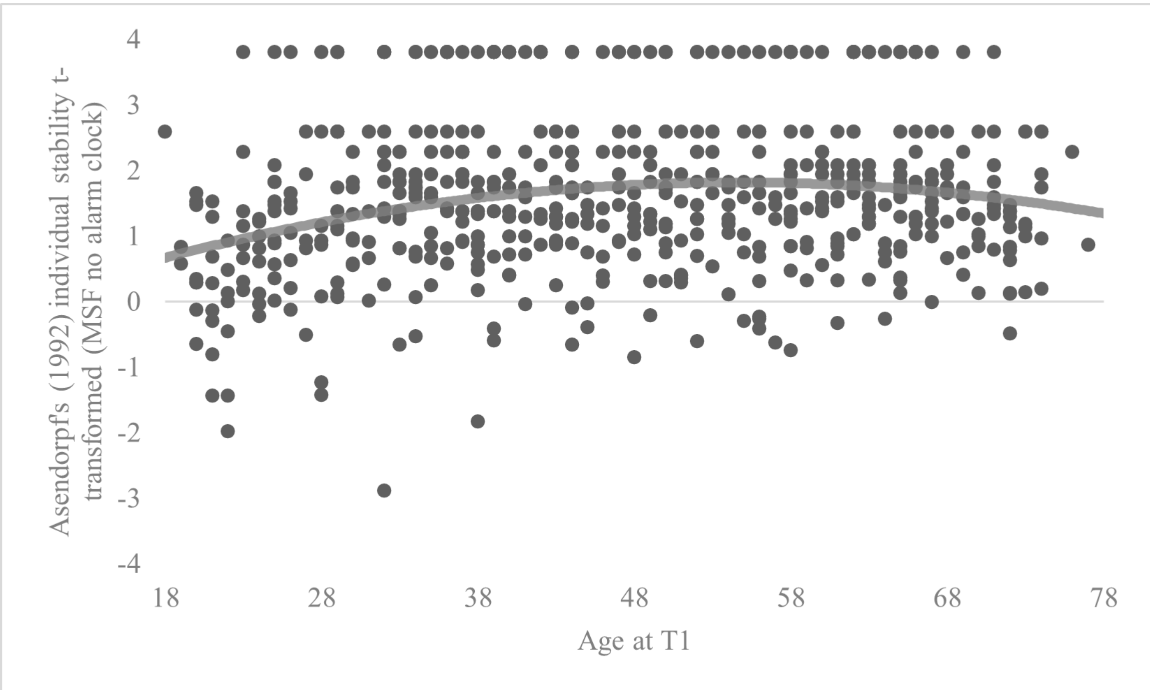

Figure A.2: Scatterplot depicting age at T1 on the x-axis and the t-transformed Asendorpf's coefficient of individual stability of MSF (mid-sleep on free days) on the y-axis.

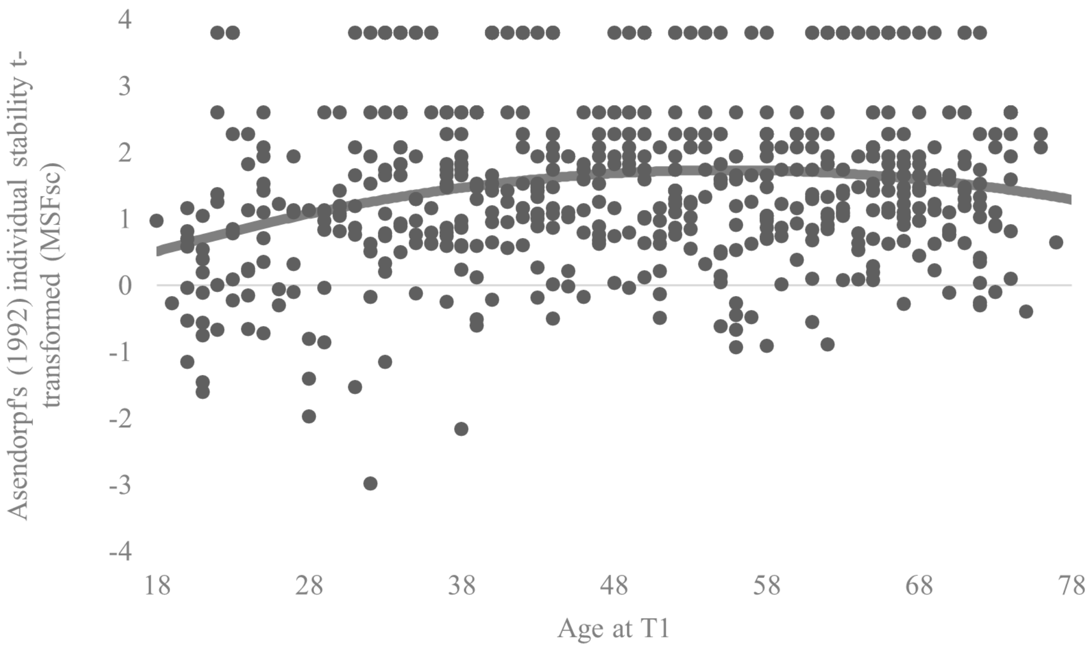

Figure A.3: Scatterplot depicting age at T1 on the x-axis and the t-transformed Asendorpf's coefficient of individual stability of MSF_{sc} (mid-sleep on free days corrected for sleep debt) on the y-axis.

stability for all three variables seems to reach its peak when participants are around 46-55-years old (*rs* ranging from .71 to .74, *ps* < .001) and then slightly decreases and reaches a plateau until older age. The test-retest correlations of MSF and MSF_{sc} of each age group did not differ from each other significantly.

As in the main study, we again ran a series of hierarchical regression analyses where we predicted individual stability coefficients (MSF and MSF_{sc} in separate models) from participant's age and the square of age at T1 (in order to account for both linear and non-linear relationships) when also controlling for retest interval. The results of the hierarchical multiple regression analysis for the individual stability of MSF and MSF_{sc} are shown in Table A.1 and Table A.2. In the models explaining the stability of MSF and MSF_{sc}, age and age square had a significant effect on the stability of mid-sleep and the addition of the variables resulted in significant improvements of the models. However, the time difference in the retest interval was not a significant predictor of stability.

A.3 Conclusion

We repeated all the analyses using both MSF and MSF_{sc} in order to ensure that our analyses were not impacted by the decision to solely look into MSF and not MSF_{sc}. As MSF_{sc} can only be calculated when participants are not using an alarm clock on

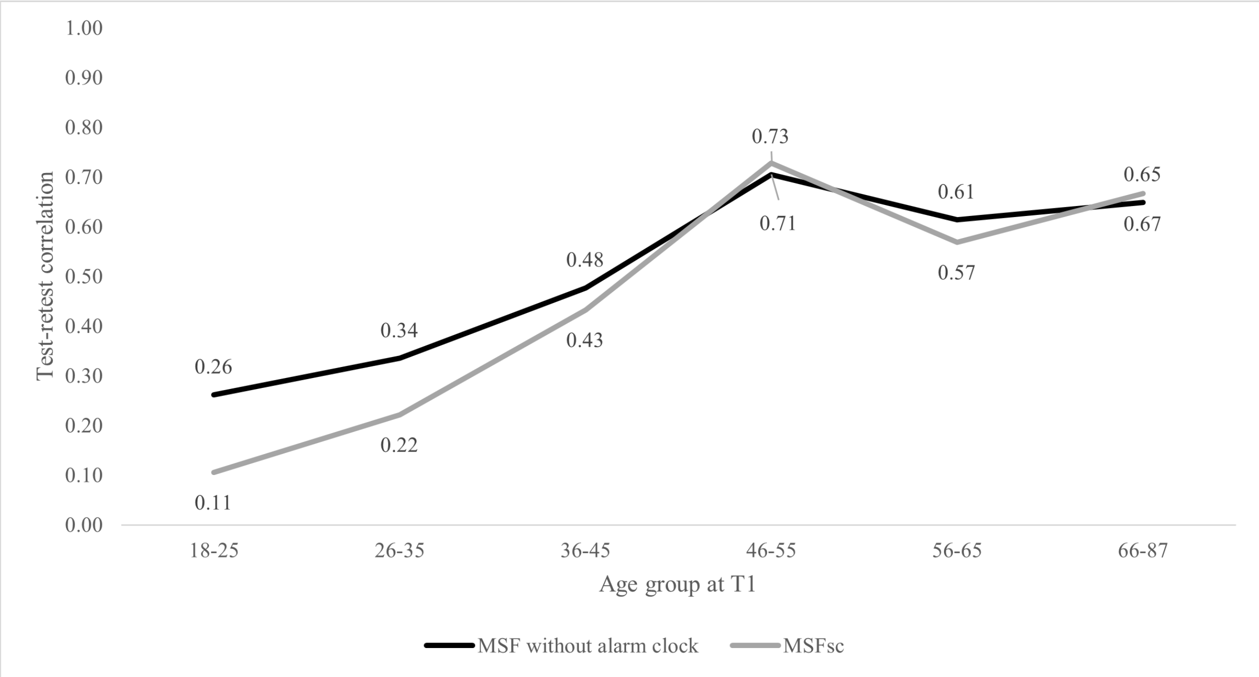

Figure A.4: Test-retest correlations of MSF (mid-sleep on free days) and MSF_{sc} (mid-sleep on free days corrected for sleep debt) by age at T1.

weekends, we had to exclude 118 participants who either had used an alarm clock at T1 or T2.

The test-retest correlations of MSF and MSF_{sc} when looking into the effect of age and time interval of filling in the questionnaire show very similar patterns. However, the coefficients seem to be slightly, but not significantly, higher in MSF than MSF_{sc}, indicating that participants' chronotypes change more when sleep debt is accounted for. This might be because even if sleep times remain the same, work hours or social demands might have changed over time.

Table A.1

Hierarchical Linear Regression Analysis Predicting Asendorpf's (1992) t-Transformed Coefficient of Individual Stability of Mid-Sleep on Free Days (MSF) From Age at T1, its Quadratic Term, and. the Difference in Years Between T1 and T2.

	Model 1				Model 2				Model 3			
	b [CI]	β	*t*	*p*	*b [CI]*	β	*t*	*p*	*b [CI]*	β	*t*	*p*
Block 1: Age at T1												
Constant	1.14 [0.82, 1.46]		7.07	<.001	-0.01 [-0.9, 0.88]		-0.02	.986	0.15 [-0.77, 1.08]		0.33	.744
Age	0.01 [0.00, 0.02]	.12	2.83	.005	0.06 [0.02, 0.10]	.83	3.12	.002	0.06 [0.02, 0.10]	.84	3.16	.002
Block 2: Quadratic age												
Quadratic term of age					0.00 [0.00, 0.00]	-.72	-2.7	.007	0.00 [0.00, 0.00]	-.73	-2.75	.006
Block 3: Time difference												
Time difference									-0.07 [-0.16, 0.03]	-.06	-1.36	.175
Adjusted R^2	0.012				0.023				0.025			
F for Change in R^2	7.99			.005	7.31			.007	1.84			.175
Effect size f^2	0.014				0.027				0.031			

Note. CI = A 95% confidence interval.

Table A.2

Hierarchical Linear Regression Analysis Predicting Asendorpf's (1992) t-Transformed Coefficient of Individual Stability of Mid-Sleep on Free Days Corrected for Sleep Debt (MSF_{sc}) From Age at T1, its Quadratic Term, and the Difference in Years Between T1 and T2.

	Model 1				Model 2				Model 3			
	b [CI]	β	*t*	*p*	*b [CI]*	β	*t*	*p*	*b [CI]*	β	*t*	*p*
Block 1: Age at T1												
Constant	0.91 [0.58, 1.24]		5.40	<.001	-0.95 [-1.87, -0.02]		-2.01	.045	-0.96 [-1.92, -0.01]		-1.98	.048
Age	0.01 [0.01, 0.02]	.15	3.64	<.001	0.10 [0.06, 0.14]	1.24	4.75	<.001	0.10 [0.06, 0.14]	1.24	4.74	<.001
Block 2: Quadratic age												
Quadratic term of age					0.00 [0.00, 0.00]	-1.11	-4.22	<.001	0.00 [0.00, 0.00]	-1.10	-4.21	<.001
Block 3: Time difference												
Time difference									0.01 [-0.09, 0.11]	.01	0.14	.893
Adjusted R^2	0.021				0.05				0.048			
F for Change in R^2	13.24			<.001	17.83			.001	0.02			.893
Effect size f^2				0.024	0.056				0.056			

Note. CI = A 95% confidence interval.

Appendix B

Hierarchical Regressions (Chapter 2, Study 2)

On the following pages, Tables B.1 and B.2 will depict the results of the hierarchical multiple regression analyses for individual stability of mid-sleep on free days and mid-sleep on workdays

Table B.1

Hierarchical Linear Regression Analysis Predicting Asendorpf's (1992) t-Transformed Coefficient of Individual Stability of Mid-Sleep on Free Days (MSF) From Age at T1, its Quadratic Term, and the Difference in Years Between T1 and T2

	Model 1				Model 2				Model 3			
	b [CI]	β	t	p	*b [CI]*	β	t	p	*b [CI]*	β	t	p
Block 1: Age at T1												
Constant	1.12 [0.85, 1.40]		7.94	<.001	-0.24 [-1.03, 0.54]		-0.61	.546	-0.04 [-0.09, 0.93]		-0.09	.929
Age	0.01 [0.00, 0.02]	.13	3.35	.001	0.07 [0.04, 0.11]	1.00	4.13	<.001	0.08 [0.04, 0.11]	1.02	4.23	<.001
Block 2: Quadratic age												
Quadratic term of age					-0.00 [-0.00, 0.00]	-.88	-2.01	<.001	-0.00 [-0.00, 0.00]	-.90	-3.74	<.001
Block 3: Time difference												
Time difference									-0.09 [-0.18, -0.00]	-.08	-2.00	.045
Adjusted R^2	0.015				0.032				0.037			
F for Change in R^2	11.22			<.001	13.31			<.001	4.02			.045
Effect size f^2	0.145				0.232				0.254			

Note. CI = A 95% confidence interval.

Table B.2

Hierarchical Linear Regression Analysis Predicting Asendorpf's (1992) t-Transformed Coefficient of Individual Stability of Mid-Sleep on Workdays (MSW) From Age at T1, its Quadratic Term, and the Difference in Years Between T1 and T2.

	Model 1				Model 2				Model 3			
	b [CI]	β	*t*	*p*	*b [CI]*	β	*t*	*p*	*b [CI]*	β	*t*	*p*
Block 1: Age at T1												
Constant	1.44 [1.13, 1.75]		9.17	<.001	-0.30 [-1.17, 0.57]		-0.68	.498	-0.38 [-1.28, 0.52]		-0.54	.516
Age	0.00 [-.0.00, 0.01]	.03	0.88	.009	0.09 [0.05, 0.12]	1.04	4.29	<.001	0.08 [0.04, 0.12]	1.03	4.26	<.001
Block 2: Quadratic age												
Quadratic term of age					-0.00 [-0.00, 0.00]	-1.02	-4.21	<.001	-0.00 [-0.00, 0.00]	-1.01	-4.17	<.001
Block 3: Time difference												
Time difference									.03 [-0.06, 0.13]	.03	0.71	.477
Adjusted R^2	.000				.024				.023			
F for Change in R^2	0.78			.377	17.69			<.001	0.51			.477
Effect size f^2	0.035				0.195				0.197			

Note. CI = A 95% confidence interval.

Appendix C

Supplemental Materials From Chapter 3

The following tables are supplemental materials from Chapter 3. They are all referred to in the text.

Table C.1

Descriptive Statistics of the Participants Who Were Excluded From the Study Because of the Use of Alarm Clock on Free Days in Comparison to Included (No Use of Alarm Clock on Free Days) Participants and Values of Independent t-Tests and Chi-Squared Test, Respectively

	Excluded participants	Included participants	t	χ^2	df	p	Effect size
N	336	2,179					
Gender (n, %)	200 (59.52%) female	1,292 (59.29%) female		0.01	1	.936	.00[a]
Age (M, SD)	47.67 (15.35)	44.85 (16.87)	2.89		2,513	.004	.17[b]
Education (n, %)				27.76	2	<.001	.11[c]
Basic Education	40 (11.90%)	115 (5.28%)					
Secondary and Secondary Vocational Education	180 (53.57%)	1,099 (50.44%)					
Higher Education	116 (34.52%)	965 (44.29%)					
NEO-PI-3 Domain scales (M, SD)							
Neuroticism	85.17 (21.85)	82.36 (21.91)	2.19		2,512	.044	.13[b]
Extraversion	101.92 (24.49)	106.14 (23.99)	-2.99		2,512	.002	.18[b]
Openness to Experience	97.89 (17.84)	103.49 (19.47)	-4.96		2,512	<.001	.29[b]
Agreeableness	119.83 (17.95)	119.22 (17.54)	0.59		2,512	.073	.03[b]
Conscientiousness	126.34 (19.60)	124.72 (20.21)	1.37		2,512	.021	.08[b]

Note. NEO-PI-3 = The NEO Personality Inventory-3; effect size: [a] = ϕ; [b] = Hedges' g; [c] = Cramer's V

Table C.2

Descriptive Statistics of the NEO-PI-3 Self- and Informant-Reported Domain and Facet Scores

	Self-ratings			Informant-ratings		
	M	*SD*	*α*	*M*	*SD*	*α*
Neuroticism	84.75	24.58	.93	80.50	25.15	.93
N1: Anxiety	15.73	5.96	.82	15.24	5.88	.82
N2: Angry Hostility	13.04	5.25	.79	13.25	6.05	.83
N3: Depression	14.04	5.66	.78	13.47	5.22	.77
N4: Self- Conscientiousness	14.65	5.24	.73	13.21	4.92	.72
N5: Impulsiveness	16.66	4.85	.68	15.46	5.20	.70
N6: Vulnerability	10.64	4.72	.80	9.87	5.18	.82
Extraversion	102.60	26.01	.93	108.86	26.75	.93
E1: Warmth	21.43	4.59	.71	23.03	4.95	.77
E2: Gregariousness	15.60	6.03	.81	16.59	6.43	.84
E3: Assertiveness	14.72	6.11	.83	16.72	6.21	.82
E4: Activity	16.66	5.95	.81	18.22	6.26	.83
E5: Excitement-Seeking	14.80	5.96	.74	14.69	5.78	.73
E6: Positive Emotion	19.39	6.11	.83	19.61	5.83	.83
Openness to Experience	106.31	22.14	.90	98.92	20.54	.89
O1: Fantasy	17.14	6.08	.83	14.92	5.27	.79
O2: Aesthetics	16.07	6.31	.81	14.91	6.39	.82
O3: Feeling	20.58	4.75	.73	19.58	4.47	.73
O4: Actions	15.11	4.61	.69	14.12	4.61	.70
O5: Ideas	17.84	6.10	.81	17.29	6.07	.82
O6: Values	19.55	3.95	.54	18.10	12.71	.46
Agreeableness	118.67	18.09	.87	120.12	22.57	.92
A1: Trust	19.34	4.63	.75	19.43	25.62	.81
A2: Straightforwardness	19.82	5.31	.74	20.38	5.72	.79
A3: Altruism	21.70	3.77	.68	23.44	4.70	.77
A4: Compliance	15.67	4.63	.66	15.84	4.98	.71
A5: Modesty	20.46	5.38	.80	20.16	6.06	.85
A6: Tender-Mindedness	21.69	4.33	.65	20.86	4.45	.72
Conscientiousness	120.76	21.4	.91	129.63	24.52	.93
C1: Competence	20.10	4.19	.69	22.45	4.47	.75
C2: Order	20.97	5.37	.77	21.12	5.87	.80
C3: Dutifulness	23.20	3.91	.64	24.44	4.36	.73
C4: Achievement Striving	18.28	5.38	.74	20.04	5.44	.77
C5: Self-Discipline	19.74	5.02	.77	21.55	5.43	.82
C6: Deliberation	18.48	5.07	.75	20.05	5.58	.80

Note. α = Cronbach alpha; NEO-PI-3 = The NEO Personality Inventory-3.

Table C.3

Hierarchical Linear Regressions Examining the Influence of the NEO-PI -3 Personality Domains (Self-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	3.74 [3.14, 4.34]		12.24	.001	5.38 [4.75, 6.01]		16.79	<.001
Block 1: NEO-PI-3 Domains								
Neuroticism	0.00 [0.00, 0.00]	.00	0.13	.900	0.00 [0.00, 0.00]	-.05	-2.36	.033
Extraversion	0.01 [0.00, 0.01]	.13	5.04	<.001	0.00 [0.00, 0.00]	.03	1.48	.218
Openness to Experience	0.01 [0.01, 0.02]	.25	10.82	<.001	0.01 [0.00, 0.01]	.12	5.30	<.001
Agreeableness	-0.01 [-0.01, -0.01]	-.14	-6.47	<.001	0.00 [0.00, 0.00]	-.01	-0.7	.536
Conscientiousness	-0.01 [-0.01, -0.01]	-.15	-6.91	<.001	-0.01 [-0.01, -0.01]	-.13	-6.66	<.001
Block 2: Sociodemographics and Season								
Age					-0.03 [-0.04, -0.03]	-.49	-23.99	<.001
Gender					-0.02 [-0.11, 0.07]	-.01	-0.40	.689
Education								
Secondary					0.24 [0.05, 0.43]	.10	2.45	.031
Higher					0.37 [0.18, 0.56]	.16	3.73	<.001
Season								
Spring/Fall					-0.06 [-0.16, 0.03]	-.02	-1.31	.233
Summer					-0.08 [-0.19, 0.03]	-.03	-1.38	.230
Adjusted R^2			.161				.343	
F for Change in R^2			83.77	<.001			99.89	<.001
Effect size f^2			.19				.53	

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 C.4

Hierarchical Linear Regressions Examining the Influence of the NEO-PI -3 Personality Facets (Self-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	2.78 [2.01, 3.54]		7.12	.001	4.83 [4.06, 5.6]		12.25	.001
Block 1: NEO-PI-3 Facets								
N1: Anxiety	0.00 [-0.01, 0.01]	.00	-0.12	.901	-0.01 [-0.02, 0.00]	-.06	-2.08	.121
N2: Angry Hostility	-0.01 [-0.03, 0.00]	-.07	-2.15	.069	0.00 [-0.02, 0.01]	-.02	-0.72	.649
N3: Depression	0.01 [0.00, 0.02]	.04	1.40	.244	0.01 [-0.01, 0.02]	.03	0.91	.523
N4: Self- Conscientiousness	0.01 [0.00, 0.03]	.06	2.19	.067	0.00 [-0.01, 0.01]	.00	0.04	.984
N5: Impulsiveness	0.00 [-0.01, 0.01]	.00	-0.13	.901	0.00 [-0.01, 0.01]	.01	0.20	.948
N6: Vulnerability	-0.01 [-0.02, 0.01]	-.03	-0.84	.504	0.00 [-0.01, 0.01]	.00	-0.04	.984
E1: Warmth	0.00 [-0.01, 0.02]	.01	0.38	.755	0.01 [0.00, 0.03]	.04	1.51	.264
E2: Gregariousness	0.00 [-0.01, 0.01]	-.02	-0.57	.682	0.00 [-0.01, 0.01]	-.01	-0.42	.865
E3: Assertiveness	0.01 [0.00, 0.02]	.03	1.12	.361	0.01 [0.00, 0.02]	.06	2.17	.108
E4: Activity	-0.02 [-0.03, 0.00]	-.08	-2.58	.027	-0.01 [-0.02, 0.00]	-.07	-2.50	.062
E5: Excitement-Seeking	0.06 [0.04, 0.07]	.28	9.44	.001	0.03 [0.02, 0.04]	.14	4.96	.001
E6: Positive Emotion	0.01 [0.00, 0.02]	.06	2.05	.082	0.00 [-0.01, 0.01]	-.01	-0.29	.899
O1: Fantasy	0.02 [0.01, 0.03]	.09	3.31	.006	0.00 [0.00, 0.01]	.02	1.01	.468
O2: Aesthetics	0.00 [-0.01, 0.00]	-.03	-1.13	.361	0.01 [0.00, 0.01]	.03	1.44	.271

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Table C.4 continued from previous page

	Model 1				Model 2			
	b [CI]	β	*t*	*p*	*b* [CI]	β	*t*	*p*
O3: Feeling	0.02 [0.01, 0.03]	.08	2.84	.015	0.01 [0.00, 0.02]	.04	1.51	.264
O4: Actions	0.00 [-0.02, 0.01]	-.01	-0.44	.734	-0.01 [-0.02, 0.00]	-.04	-1.43	.271
O5: Ideas	0.00 [-0.01, 0.01]	.01	0.49	.721	0.01 [0.00, 0.02]	.03	1.24	.353
O6: Values	0.04 [0.03, 0.06]	.14	6.06	.001	0.01 [0.00, 0.03]	.04	1.82	.204
A1: Trust	-0.01 [-0.02, 0.00]	-.04	-1.89	.111	-0.01 [-0.02, 0.00]	-.04	-1.79	.205
A2: Straightforwardness	0.02 [0.01, 0.04]	.11	4.50	.001	0.02 [0.01, 0.03]	.10	4.19	.001
A3: Altruism	0.01 [0.00, 0.03]	.04	1.52	.213	0.00 [-0.01, 0.02]	.01	0.29	.899
A4: Compliance	-0.02 [-0.03, -0.01]	-.08	-2.89	.015	-0.01 [-0.02, 0.00]	-.04	-1.51	.264
A5: Modesty	-0.03 [-0.04, -0.02]	-.12	-4.69	.001	-0.01 [-0.02, 0.00]	-.06	-2.33	.090
A6: Tender-Mindedness	-0.02 [-0.03, -0.01]	-.06	-2.81	.015	0.00 [-0.01, 0.01]	-.01	-0.57	.755
C1: Competence	-0.01 [-0.03, 0.01]	-.03	-0.98	.427	0.00 [-0.02, 0.01]	-.01	-0.36	.890
C2: Order	0.01 [0.00, 0.02]	.05	2.18	.067	0.00 [-0.01, 0.01]	.00	-0.02	.984
C3: Dutifulness	-0.01 [-0.03, 0.00]	-.05	-1.68	.164	0.00 [-0.01, 0.02]	.00	0.05	.984
C4: Achievement Striving	-0.02 [-0.03, -0.01]	-.08	-2.84	.015	-0.02 [-0.03, -0.01]	-.07	-2.91	.024
C5: Self-Discipline	-0.02 [-0.03, -0.01]	-.08	-2.81	.015	-0.03 [-0.04, -0.01]	-.11	-3.90	.001
C6: Deliberation	0.01 [0.00, 0.02]	.04	1.46	.229	0.01 [0.00, 0.02]	.04	1.51	.264
Block 2: Sociodemographics and Season								
Age					-0.03 [-0.04, -0.03]	-.46	-18.97	.001

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Table C.4 continued from previous page

	Model 1				Model 2			
	b [CI]	β	*t*	*p*	*b* [CI]	β	*t*	*p*
Gender					-0.06 [-0.16, 0.04]	-.02	-1.18	.374
Education								
Secondary					0.21 [0.02, 0.40]	.09	2.19	.108
Higher					0.37 [0.17, 0.56]	.15	3.63	.001
Season								
Spring/Fall					-0.08 [-0.18, 0.01]	-.03	-1.66	.247
Summer					-0.08 [-0.19, 0.03]	-.03	-1.41	.271
Adjusted R^2			.248				.364	
F for Change in R^2			24.68	.001			65.34	.001
Effect size f^2			.35				.60	

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 C.5

Hierarchical Linear Regressions Examining the Influence of the NEO-PI -3 Personality Domains (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	3.95 [3.39, 4.51]		13.81	<.001	5.25 [4.66, 5.84]		17.43	<.001
Block 1: NEO-PI-3 Domains								
Neuroticism	0.00 [-0.01, 0.00]	-.08	-3.00	.003	0.00 [0.00, 0.00]	-.04	-1.56	.189
Extraversion	0.00 [0.00, 0.01]	.10	3.76	<.001	0.00 [0.00, 0.00]	.06	2.58	.018
Openness to Experience	0.01 [0.01, 0.02]	.23	9.14	<.001	0.01 [0.00, 0.01]	.10	4.5	<.001
Agreeableness	0.00 [-0.01, 0.00]	-.08	-3.27	.001	0.00 [0.00, 0.00]	-.01	-0.4	.689
Conscientiousness	-0.01 [-0.01, -0.01]	-.20	-8.6	<.001	-0.01 [-0.01, -0.01]	-.15	-7.1	<.001
Block 2: Sociodemographics and Season								
Age					-0.03 [-0.04, -0.03]	-.49	-25.71	<.001
Gender					-0.03 [-0.12, 0.07]	-.01	-0.57	.627
Education								
Secondary					0.26 [0.07, 0.45]	.11	2.65	.018
Higher					0.42 [0.22, 0.62]	.18	4.19	<.001
Season								
Spring/Fall					-0.07 [-0.17, 0.02]	-.03	-1.48	.191
Summer					-0.07 [-0.19, 0.04]	-.02	-1.23	.269
Adjusted R^2			.118				.434	
F for Change in R^2			56.09	<.001			117.82	<.001
Effect size f^2			.14				.53	

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 C.6

Hierarchical Linear Regressions Examining the Influence of the NEO-PI -3 Personality Facets (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	β	t	p
Intercept	3.24 [2.47, 4.01]		8.27	<.001	4.89 [4.14, 5.64]		12.8	<.001
Block 1: NEO-PI-3 Facets								
N1: Anxiety	0.00 [-0.02, 0.01]	-.01	-0.30	.829	-0.01 [-0.02, 0]	-.05	-1.76	.224
N2: Angry Hostility	-0.02 [-0.04, -0.01]	-.11	-3.11	.009	-0.01 [-0.02, 0.01]	-.03	-1.05	.465
N3: Depression	0.01 [-0.01, 0.02]	.04	1.19	.444	0.01 [0.00, 0.02]	.04	1.47	.319
N4: Self- Conscientiousness	0.01 [-0.01, 0.02]	.04	1.18	.444	0.00 [-0.01, 0.01]	-.01	-0.22	.901
N5: Impulsiveness	-0.01 [-0.02, 0.01]	-.03	-1.11	.471	0.00 [-0.01, 0.01]	-.01	-0.46	.857
N6: Vulnerability	0.01 [-0.01, 0.03]	.05	1.35	.379	0.01 [0.00, 0.03]	.05	1.47	.319
E1: Warmth	-0.01 [-0.02, 0.01]	-.03	-0.85	.563	0.01 [-0.01, 0.02]	.03	1.03	.465
E2: Gregariousness	0.01 [-0.01, 0.02]	.03	0.97	.498	0.01 [0.00, 0.02]	.06	2.01	.180
E3: Assertiveness	0.00 [-0.01, 0.01]	-.01	-0.22	.858	0.01 [0.00, 0.02]	.04	1.54	.319
E4: Activity	-0.01 [-0.03, 0.00]	-.07	-2.12	.093	-0.01 [-0.02, 0.00]	-.05	-1.85	.223
E5: Excitement-Seeking	0.04 [0.03, 0.06]	.22	7.08	<.001	0.01 [0.00, 0.02]	.05	1.82	.223
E6: Positive Emotion	0.02 [0.01, 0.03]	.09	2.78	.022	0.00 [-0.01, 0.01]	.01	0.38	.866
O1: Fantasy	0.01 [0.00, 0.03]	.06	2.20	.084	0.01 [-0.01, 0.02]	.03	1.01	.465
O2: Aesthetics	0.00 [0.00, 0.01]	.03	0.99	.498	0.01 [0.00, 0.02]	.06	2.59	.060

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Table C.6 continued from previous page

	Model 1				Model 2			
	b	*β*	*t*	*p*	*b*	*β*	*t*	*p*
O3: Feeling	0.02 [0.00, 0.04]	.08	2.54	.037	0.00 [-0.01, 0.02]	.01	0.26	.901
O4: Actions	0.01 [0.00, 0.02]	.04	1.40	.369	0.00 [-0.02, 0.01]	-.01	-0.42	.866
O5: Ideas	0.00 [-0.01, 0.01]	.01	0.41	.820	0.01 [0.00, 0.02]	.03	1.07	.465
O6: Values	0.03 [0.01, 0.04]	.08	3.51	.001	0.01 [0.00, 0.02]	.03	1.28	.404
A1: Trust	0.00 [-0.01, 0.01]	.01	0.29	.829	0.00 [-0.01, 0.01]	.00	0.19	.901
A2: Straightforwardness	0.03 [0.02, 0.04]	.13	4.63	<.001	0.02 [0.01, 0.03]	.08	3.15	.018
A3: Altruism	0.00 [-0.01, 0.02]	.02	0.49	.779	0.00 [-0.01, 0.02]	.02	0.53	.822
A4: Compliance	-0.03 [-0.04, -0.01]	-.12	-3.82	<.001	-0.02 [-0.03, 0.00]	-.07	-2.39	.077
A5: Modesty	-0.01 [-0.02, 0.01]	-.03	-1.07	.478	-0.01 [-0.02, 0.00]	-.03	-1.09	.465
A6: Tender-Mindedness	-0.04 [-0.05, -0.03]	-.15	-5.8	<.001	-0.02 [-0.03, 0.00]	-.06	-2.65	.058
C1: Competence	0.00 [-0.02, 0.02]	.01	0.29	.829	0.00 [-0.02, 0.02]	.00	-0.06	.976
C2: Order	0.00 [-0.01, 0.01]	.02	0.66	.691	0.00 [-0.01, 0.01]	-.01	-0.36	.866
C3: Dutifulness	-0.02 [-0.03, 0.00]	-.06	-1.83	.168	0.00 [-0.02, 0.02]	.00	0.01	.992
C4: Achievement Striving	0.00 [-0.01, 0.01]	.00	0.07	.943	0.00 [-0.02, 0.01]	-.02	-0.73	.671
C5: Self-Discipline	-0.03 [-0.04, -0.01]	-.12	-3.40	.005	-0.02 [-0.03, -0.01]	-.10	-3.24	.012
C6: Deliberation	0.00 [-0.01, 0.02]	.02	0.58	.733	0.00 [-0.01, 0.01]	.01	0.22	.901
Block 2: Sociodemographics and Season								
Age					-0.03 [-0.04, -0.03]	-.48	-22.45	<.001

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Table C.6 continued from previous page

	Model 1				Model 2			
	b	*β*	*t*	*p*	*b*	*β*	*t*	*p*
Gender					-0.06 [-0.16, 0.05]	-.02	-1.07	.465
Education								
Secondary					0.25 [0.06, 0.44]	.11	2.52	.062
Higher					0.39 [0.19, 0.6]	.17	3.86	<.001
Season								
Spring/Fall					-0.09 [-0.19, 0.01]	-.03	-1.75	.224
Summer					-0.08 [-0.2, 0.03]	-.03	-1.4	.339
Adjusted R^2			.179				.354	
F for Change in R^2			15.99	<.001			92.38	<.001
Effect size f^2			.24				.58	

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 C.7
Results of the Item Analysis That Led to the Development of the Weighted Personality Item Score (Polypersonality Score) for Self-and Informant-Reports Separately

Item number	**Item name**	**Facet**	**Weight**
Self-reports			
#55	I waste a lot of time before settling down to work.*	C5: Self-discipline	-.099
#230	I'm something of a "workaholic".	C4: Achievement striving	-.071
#112	I tend to avoid movies that are shocking or scary.*	E5: Excitement seeking	.062
#179	I believe all human beings are worthy of respect.	A6: Tender mindedness	-.038
#225	I try to go to work or school even when I'm not feeling well	C3: Dutifulness	-.031
#233	I have a wide range of intellectual interests.	O5: Openness to ideas	.024
#38	I am sometimes completely absorbed in music I am listening to.	O2: Openness to aesthetics	.020
#88	I believe we should look to our religious authorities for decisions on moral issues.*	O6: Openness to values	.019
#202	I like loud music.	E5: Excitement seeking	.019
#187	Social gatherings are usually boring to me.*	E2: Gregariousness	.017
#23	I often enjoy playing with theories or abstract ideas	O5: Openness to ideas	.013
#8	I'm not really interested in the arts.*	O2: Openness to aesthetics	.013
#158	Certain kinds of music have an endless fascination for me.	O2: Openness to aesthetics	.008
#33	I don't get much pleasure from chatting with people.*	E1: Warmth	.008

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Table C.7 – *Continued from previous page*

Item number	Item name	Facet	Weight
#82	I have sometimes done things just "kicks" or "thrills".	E5: Excitement seeking	.007
#168	I believe variety is the spice of life.	O4: Openness to actions	.006
#98	I am intrigued by the patterns I find in art and nature.	O2: Openness to aesthetics	.005
#10	I don't mind a little clutter in my room.*	C2: Order	-.003
#113	I sometimes lose interest when people talk about very abstract, theoretical matters.*	O5: Openness to ideas	.001
Informant-reports			
#55	I waste a lot of time before settling down to work.*	C5: Self-discipline	-.040
#85	I am a productive person who always gets the job done.	C5: Self-discipline	-.001
#97	I really feel the need for other people if I am by myself for long.	E2: Gregariousness	.024
#98	I am intrigued by the patterns I find in art and nature.	O2: Openness to aesthetics	.006
#120	I always consider the consequences before I take action.	C6: Deliberation	-.022
#157	I'd rather vacation at a popular beach than an isolated cabin in the woods.	E2: Gregariousness	.002
#230	I'm something of a "workaholic".	C4: Achievement striving	-.056

Note. * = reverse coded

Table C.8

Predictive Validity of Pesonality PGS and Prediction of Personality from Chronotype PGS (Separate for Self-and Informant Reports)

	Self-reports		Informant-reports	
	Regression coefficients	*p*	Regression coefficients	*p*
Predictive validity of personality PGSs				
Neuroticism	2.73	<.001	2.33	<.001
N1: Anxiety	.65	<.001	.50	<.001
N2: Angry Hostility	.67	<.001	.66	<.001
N3: Depression	.52	<.001	.34	.018
N4: Self- Conscientiousness	.30	<.001	.18	.290
N5: Impulsiveness	.37	<.001	.34	.018
N6: Vulnerability	.24	<.006	.31	.033
Extraversion	-.11	.085	-.33	.881
E1: Warmth	.03	.935	.00	.988
E2: Gregariousness	-.04	.935	-.03	.978
E3: Assertiveness	-.13	.935	-.23	.250
E4: Activity	-.10	.748	-.01	.988
E5: Excitement-Seeking	.06	.243	.08	.808
E6: Positive Emotion	.07	.935	-.13	.631
Openness to Experience	-.36	.935	-.56	.460
O1: Fantasy	-.04	.748	-.10	.765
O2: Aesthetics	-.02	.935	-.05	.906
O3: Feeling	-.06	.935	.04	.906
O4: Actions	-.03	.935	-.17	.250
O5: Ideas	-.19	.935	-.15	.588
O6: Values	-.03	.364	-.14	.250
Agreeableness	.01	.935	.35	.802
A1: Trust	-.04	.974	.12	.631
A2: Straightforwardness	.11	.935	.24	.197
A3: Altruism	-.02	.748	.00	.988
A4: Compliance	-.09	.935	-.05	.906
A5: Modesty	.10	.748	.04	.906
A6: Tender-Mindedness	-.04	.748	.00	.988
Conscientiousness	-.39	.935	.18	.906
C1: Competence	-.08	.748	-.03	.906
C2: Order	-.20	.748	-.09	.802
C3: Dutifulness	-.01	.265	.14	.341

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Table C.8 – *Continued from previous page*

	Self-reports		Informant-reports	
	Regression coefficients	*p*	Regression coefficients	*p*
C4: Achievement Striving	.01	.935	.05	.906
C5: Self-Discipline	-.13	.935	.01	.988
C6: Deliberation	.01	.651	.09	.802
Predicting NEO-PI-3 personality domains and facets from chronotype PGS				
Neuroticism	.52	.660	-.05	.955
N1: Anxiety	.12	.509	.15	.521
N2: Angry Hostility	.13	.660	-.09	.628
N3: Depression	.13	.660	.05	.734
N4: Self- Conscientiousness	.07	.745	.08	.627
N5: Impulsiveness	.02	.927	-.16	.435
N6: Vulnerability	.04	.811	-.07	.628
Extraversion	-.24	.811	-.88	.391
E1: Warmth	-.13	.660	-.19	.315
E2: Gregariousness	-.07	.762	-.18	.462
E3: Assertiveness	.11	.672	-.12	.627
E4: Activity	.13	.660	-.04	.84
E5: Excitement-Seeking	-.14	.660	-.28	.114
E6: Positive Emotion	-.13	.660	-.08	.628
Openness to Experience	-.72	.558	-.79	.315
O1: Fantasy	-.07	.745	-.27	.114
O2: Aesthetics	-.24	.509	-.29	.168
O3: Feeling	-.01	.981	.08	.627
O4: Actions	-.10	.660	-5.30	.627
O5: Ideas	-.29	.509	-3.12	.627
O6: Values	-.03	.822	.93	.315
Agreeableness	-.33	.660	.39	.627
A1: Trust	-.09	.660	-.05	.711
A2: Straightforwardness	-.15	.660	-.08	.628
A3: Altruism	-.05	.745	.02	.877
A4: Compliance	-.10	.660	.11	.627
A5: Modesty	.06	.745	.33	.114
A6: Tender-Mindedness	-.01	.931	.07	.627
Conscientiousness	-.15	.822	.00	.964
C1: Competence	-.03	.822	.19	.391
C2: Order	.00	.984	.14	.391

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Table C.8 – *Continued from previous page*

	Self-reports		Informant-reports	
	Regression coefficients	*p*	Regression coefficients	*p*
C3: Dutifulness	-.10	.660	.11	.627
C4: Achievement Striving	.09	.696	.36	.047
C5: Self-Discipline	.09	.672	.18	.462
C6: Deliberation	-.21	.509	.39	.627
Polypersonality Score	-.01	.002	-.01	<.001

Note. NEO-PI-3 = The NEO Personality Inventory-3; PGS = polygenic score. *P*-values were adjusted for the false discovery rate. Regression coefficients were standardised. For the predictive valididity of personality PGSs, NEO-PI-3 personality domains and facets were predicted from personality PGSs

Table C.9

Results of the Item Analysis That Led to the Development of the Weighted Personality Item Score (Polypersonality Score) for Combined Self-and Informant-Reports

Item number	Item name	Facet	Weight
#55	I waste a lot of time before settling down to work.*	C5: Self-discipline	-.101
#230	I'm something of a "workaholic".	C4: Achievement striving	-.08
#112	I tend to avoid movies that are shocking or scary.*	E5: Excitement seeking	.055
#233	I have a wide range of intellectual interests.	O5: Openness to ideas	.029
#38	I am sometimes completely absorbed in music I am listening to.	O2: Openness to aesthetics	.022
#179	I believe all human beings are worthy of respect.	A6: Tender mindedness	-.021
#157	I'd rather vacation at a popular beach than an isolated cabin in the woods.	E2: Gregariousness	.019
#88	I believe we should look to our religious authorities for decisions on moral issues.*	O6: Openness to values	.018
#33	I don't get much pleasure from chatting with people.*	E1: Warmth	.011
#225	I try to go to work or school even when I'm not feeling well	C3: Dutifulness	-.011
#174	I feel that I am no better than others, no matter what their condition.	A5: Modesty	-.010
#97	I really feel the need for other people if I am by myself for long.	E2: Gregariousness	.010
#187	Social gatherings are usually boring to me.*	E2: Gregariousness	.010
#202	I like loud music.	E5: Excitement seeking	.010
#113	I sometimes lose interest when people talk about very abstract, theoretical matters.*	O5: Openness to ideas	.009

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Table C.9 – *Continued from previous page*

Item number	Item name	Facet	Weight
#8	I'm not really interested in the arts.*	O2: Openness to aesthetics	.009
#120	I always consider the consequences before I take action.	C6: Deliberation	-.008
#98	I am intrigued by the patterns I find in art and nature.	O2: Openness to aesthetics	.007
#82	I have sometimes done things just "kicks" or "thrills".	E5: Excitement seeking	.007
#168	I believe variety is the spice of life.	O4: Openness to actions	.004
#25	I'm pretty good about pacing myself so as to get things done on time.	C5: Self-discipline	-.004
#92	Many people think of me as somewhat cold and distant.*	E1: Warmth	.003
#213	I would have difficulty just letting my mind wander without control or guidance.*	O1: Openness to fantasy	.001

Note. * = reverse coded

Table C.10

Standardised Regression Coefficients of the Polygenic Scores (PGS) of Personality Predicting Their Corresponding Personality Trait and Facets. These were Controlled for the Twenty Principal Components and Sociodemographic Variables.

	Regression coefficient	*p*
Neuroticism	2.59	<.001
N1: Anxiety	.58	<.001
N2: Angry Hostility	.67	<.001
N3: Depression	.44	<.001
N4: Self- Conscientiousness	.25	<.001
N5: Impulsiveness	.36	<.001
N6: Vulnerability	.28	<.001
Extraversion	-.18	.709
E1: Warmth	.04	.838
E2: Gregariousness	-.03	.846
E3: Assertiveness	-.17	.390
E4: Activity	-.05	.838
E5: Excitement-Seeking	.05	.838
E6: Positive Emotion	-.02	.846
Openness to Experience	-.49	.440
O1: Fantasy	-.07	.789
O2: Aesthetics	-.05	.838
O3: Feeling	-.02	.846
O4: Actions	-.10	.540
O5: Ideas	-.18	.290
O6: Values	-.07	.582
Agreeableness	.13	.709
A1: Trust	.03	.844
A2: Straightforwardness	.17	.253
A3: Altruism	-.02	.846
A4: Compliance	-.07	.732
A5: Modesty	.06	.838
A6: Tender-Mindedness	-.03	.838
Conscientiousness	-.25	.709
C1: Competence	-.07	.732
C2: Order	-.17	.290
C3: Dutifulness	.04	.838
C4: Achievement Striving	.01	.889
C5: Self-Discipline	-.10	.582
C6: Deliberation	.04	.838

Note. The *p*-values were adjusted for the false discovery rate.

Table C.11

Hierarchical Linear Regressions Examining the Influence of the NEO-PI-3 Personality Facets (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	2.68 [1.81, 3.55]		6.02	<.001	4.79 [3.91, 5.66]		10.75	<.001
Block 1: NEO-PI-3 Facets								
N1: Anxiety	0.00 [-0.01, 0.02]	.00	0.13	.924	-0.02 [-0.03, 0.00]	-.07	-2.26	.117
N2: Angry Hostility	-0.03 [-0.04, -0.01]	-.11	-3.35	.003	-0.01 [-0.02, 0.00]	-.04	-1.32	.304
N3: Depression	0.01 [0.00, 0.03]	.05	1.62	.225	0.01 [-0.01, 0.02]	.04	1.25	.317
N4: Self- Conscientiousness	0.02 [0.00, 0.03]	.06	2.06	.100	0.00 [-0.01, 0.02]	.01	0.23	.867
N5: Impulsiveness	-0.01 [-0.03, 0.01]	-.03	-1.18	.377	0.00 [-0.02, 0.01]	-.01	-0.43	.754
N6: Vulnerability	0.00 [-0.01, 0.02]	.02	0.49	.750	0.01 [-0.01, 0.03]	.03	1.04	.411
E1: Warmth	0.00 [-0.02, 0.02]	.00	0.14	.924	0.01 [0.00, 0.03]	.04	1.43	.274
E2: Gregariousness	-0.01 [-0.02, 0.01]	-.02	-0.78	.626	0.00 [-0.01, 0.01]	.01	0.44	.754
E3: Assertiveness	0.00 [-0.01, 0.02]	.02	0.58	.732	0.01 [0.00, 0.02]	.06	1.93	.149
E4: Activity	-0.01 [-0.03, 0.00]	-.07	-2.06	.100	-0.01 [-0.02, 0.00]	-.06	-1.87	.149
E5: Excitement-Seeking	0.06 [0.05, 0.08]	.28	9.40	<.001	0.03 [0.02, 0.04]	.13	4.21	<.001
E6: Positive Emotion	0.01 [0.00, 0.02]	.05	1.52	.249	-0.01 [-0.02, 0.01]	-.02	-0.86	.499
O1: Fantasy	0.02 [0.01, 0.04]	.10	3.40	.003	0.01 [0.00, 0.02]	.04	1.36	.300
O2: Aesthetics	0.00 [-0.01, 0.01]	-.01	-0.54	.736	0.01 [0.00, 0.02]	.04	1.89	.149

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Table C.11 continued from previous page

	Model 1				Model 2			
	b [CI]	β	*t*	*p*	*b* [CI]	β	*t*	*p*
O3: Feeling	0.03 [0.01, 0.05]	.10	3.38	.003	0.01 [0.00, 0.03]	.04	1.45	.274
O4: Actions	0.00 [-0.01, 0.02]	.01	0.21	.924	-0.01 [-0.03, 0.01]	-.03	-1.30	.304
O5: Ideas	0.00 [-0.01, 0.01]	-.01	-0.34	.843	0.01 [-0.01, 0.02]	.02	0.92	.479
O6: Values	0.05 [0.03, 0.07]	.13	5.46	.001	0.01 [0.00, 0.03]	.04	1.73	.191
A1: Trust	-0.01 [-0.02, 0.01]	-.02	-0.74	.626	-0.01 [-0.02, 0.01]	-.03	-1.09	.400
A2: Straightforwardness	0.04 [0.02, 0.05]	.14	5.35	<.001	0.03 [0.01, 0.04]	.10	4.35	<.001
A3: Altruism	0.01 [0.00, 0.03]	.04	1.48	.249	0.01 [-0.01, 0.02]	.02	0.61	.650
A4: Compliance	-0.03 [-0.05, -0.02]	-.11	-3.84	<.001	-0.02 [-0.03, 0.00]	-.06	-2.24	.117
A5: Modesty	-0.02 [-0.04, -0.01]	-.10	-3.67	<.001	-0.01 [-0.02, 0.00]	-.05	-1.99	.149
A6: Tender-Mindedness	-0.04 [-0.05, -0.02]	-.11	-4.73	<.001	-0.01 [-0.03, 0.00]	-.04	-1.92	.149
C1: Competence	0.00 [-0.02, 0.02]	.00	0.06	.956	0.00 [-0.02, 0.02]	.00	-0.09	.955
C2: Order	0.01 [0.00, 0.02]	.04	1.41	.262	0.00 [-0.01, 0.01]	-.01	-0.26	.867
C3: Dutifulness	-0.02 [-0.04, 0.00]	-.06	-1.87	.143	0.00 [-0.02, 0.02]	.00	0.05	.961
C4: Achievement Striving	-0.01 [-0.02, 0.00]	-.04	-1.47	.249	-0.01 [-0.03, 0.00]	-.05	-1.88	.149
C5: Self-Discipline	-0.02 [-0.04, -0.01]	-.09	-2.72	.021	-0.03 [-0.04, -0.01]	-.10	-3.40	.007
C6: Deliberation	0.01 [-0.01, 0.02]	.02	0.77	.626	0.00 [-0.01, 0.02]	.02	0.63	.650
Block 2: Sociodemographics and Season								
Age					-0.03 [-0.03, -0.03]	-.45	-18.86	<.001

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Table C.11 continued from previous page

	Model 1				Model 2			
	b [CI]	β	*t*	*p*	*b* [CI]	β	*t*	*p*
Gender					-0.08 [-0.18, 0.02]	-.03	-1.55	.242
Education								
Secondary					0.21 [0.02, 0.40]	.09	2.22	.117
Higher					0.36 [0.16, 0.55]	.15	3.59	<.001
Season								
Spring/Fall					-0.09 [-0.19, 0.00]	-.03	-1.9	.149
Summer					-0.09 [-0.20, 0.02]	-.03	-1.64	.214
Adjusted R^2			.256				.371	
F for Change in R^2			26.03	<.001			65.82	<.001
Effect size f^2			.36				.62	

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.

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