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# Mismatch of Sleep and Work Arrangements among Research and Development Employees and Personalisation of Sleep Studies

ERVE SÕÕRU

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**Declaration:**
*Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for doctoral or equivalent academic degree.*

Erve Sõõru

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signature


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# Teadus- ja arendustöötajate une ja töökorralduse ebakõlad ning uneuuringute personaliseerimine

ERVE SÕÕRU

TALTECH KIRJASTUS

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## List of Publications and Invention

The thesis has been prepared based on the following author's publications and invention:

I Hazak, Aaro; **Sõõru, Erve**; Hein, Heili; Männasoo, Kadri (2018). Effects of work arrangements on the sleep regimen of creative R&D employees. International Journal of Occupational Safety and Ergonomics. Taylor & Francis. Epub ahead of print. DOI: 10.1080/10803548.2018.1504854 (Web of Science, Scopus)

II **Sõõru, Erve**; Hazak, Aaro; Rebane, Marit (2018). Does chronotype restrict the employment options of creative R&D professionals? Biological Rhythm Research. Taylor & Francis. Epub ahead of print. DOI: 10.1080/09291016.2018.1528681 (Web of Science, Scopus)

III Invention: A method and device for personalized pulse oximetry; Owners: RES-MEDICA OÜ, ELIKO Tehnoloogia Arenduskeskus OÜ; Authors: **Erve Sõõru**, Mart Min, Paul Annus, Raul Land; Priority number: US 61/771,903; Priority date: 03.03.2013.

Refer to the Curriculum vitae for other related publications and conference proceedings on the topic areas of the thesis.

## Author's Contribution to the Publications and Invention

Contribution of the author to the papers and the invention in this thesis is as follows:

I Design of sleep related aspects of the study, interpretation of sleep related results of the study, corresponding author of the manuscript.

II Design of sleep related aspects of the study, interpretation of sleep related results of the study, corresponding author of the manuscript.

III Author of the idea for the invention, selection of the method and the device for the invention in personalised pulse oximetry, communication with patent agencies, contribution to the patent application writing.

# Introduction

Sleep is a key element of our everyday functioning, which must be valued throughout one`s life to maintain good health and stamina. The timing of work and other aspects of work organisation and health can affect an individual's sleep patterns and overall quality of life. In today's society, more and more people are working at an inappropriate time for their health (Saulle et al., 2018). According to evidence, shifts and night work arrangements threaten sleep and health (Costa, 1996; Kantermann et al., 2010; Ohayon et al., 2010; Karhula et al., 2013) while Åkerstedt (2003), for example, reports that it is not entirely clear that shift work, which has lasted for a long time, causes sleep problems. The usual `nine-to-five` schedule disregards the needs of individual employees, which may result in a productivity decrease, including among creative research and development (R&D) employees (Ruubel and Hazak, 2018).

Chronotype characterises an individual's daily activity period preference. People are divided into morning-, neither- or evening-type based on their sleep, work, eating, or spending their free time according to their inherent circadian rhythms (Adan et al., 2012; Roenneberg, 2012); but all the three types often have to work with similar schedules. Approximately 60% of individuals are neither-type while approximately 40% belong to morning- or evening-type (Roenneberg, 2012; Fisher et al., 2017), which highlights the extent of the sleep and work schedule mismatch. The morning- and evening-types might work at an unfitting time considering their performance and health. This motivated the studies in the two papers underlying this thesis to investigate which types of employees feel that work constrains their sleep habits and whether the arrangement of work (e.g. flexibility in working time, possibilities for distance work, proportion of creative work) has an impact on how much work limits the sleep habits **(Publication I)**, and whether chronotype limits the employment options of an individual **(Publication II)**. The timing and location of work and other aspects of how work is organised may have a strong effect on sleep habits and overall wellbeing for employees, and chronotype, in turn, may affect the employment options of people.

Sleep medicine is a rather new discipline. While many individuals do not realise that they might have any sleep problems, latest research has demonstrated an increase of insomnia, sleep-disordered breathing and other sleep disorders (Hillman and Lack, 2013; Punjabi, 2008). A person may not suspect himself of a prolonged sleep disorder and probably does not know how important sleep quality is for good health and work ability. There are numerous diagnostic methods available to diagnose sleep disordered breathing (SDB) and other sleep disorders. A key sensor for evaluation of respiratory events in sleep studies (e.g. polysomnography) is pulse oximetry. This is a simple method for screening hypoxaemia, sleep apnea and other SDB. Some of the occupations in which sleep related problems require closer attention are, for example, rescue workers, law enforcement officers, soldiers, construction workers, and drivers. It would be highly beneficial to validate their health status prior to work permission, but validation in clinical surroundings is cumbersome and expensive. While usage of wearable pulse oximeters enables generally sleep study at home during normal night sleep, any manipulation of the results has to be excluded. For example, in everyday work of the author of the thesis as a pulmonologist, situations where a patient has given the diagnostic device to a third person have been met. This motivates the invention **(Publication III)** on the description of a method and device for personalised pulse oximetry of a patient to investigate the sleep apnea syndrome wherein a wearable pulse oximeter supplied for the patient for home use sleep study is able to identify whether the device is used by a third person during the period or not. After the implementation of the European Union directive 2014/85/EU on driver licensing in obstructive sleep apnea, the risk of manipulations of pulse oximetry results is particularly high in commercial drivers.

The hypotheses of the thesis and the consequent aim of the publications is outlined in Section 1.7. The novelty of the research presented in this thesis is reflected in a unique study how the chronotype may impact employment options in R&D jobs. Second, the author of the thesis and her colleagues invented a method and a device for individual identification during pulse oximetry and related sleep studies.

For Publications I and II, the data collected via a repeated questionnaire study of Estonian creative researchers and development workers was used. This is a specific type of employees whose work outcome is strongly determined by the creative capacity of the employee and driven by how rested the person is. The morningness-eveningness type of a creative R&D employee may limit their employment options as well as impact the effects of work arrangements on their sleep. For the quantitative statistical analysis, ordinary least squares (OLS) regressions, ordered probit regressions and recursive structural equation modelling (SEM) estimates have been used. These pilot studies seek to contribute to the investigation of the underlying matters but warrant future studies to gather further evidence.

The publications and the invention have been presented at the European Sleep Research Congresses (Tallinn, 2014 and Basel, 2018), the Nordic Sleep Conference (Gothenburg, 2015), the Global Conference on Business and Finance (San Jose, 2018) and at Tallinn University of Technology research seminars. The author of the thesis has been the National Representative as Study Collaborator in the European Sleep Research Society's projects "Wake Up Bus" (2015) and "Variability in recording and scoring of respiratory events during sleep in Europe: a need for uniform standards" (2016). The author of the thesis is currently leader of the working group of the projects "First-line diagnostic guidelines of sleep disorders among adults" (2019) and "Estonian eHealth for screening obstructive sleep apnea among drivers" (2019), strongly related to the topic areas of this thesis.

The following sections of the thesis outline the physiological background to sleep, circadian rhythm regulation and chronotype. A discussion of the linkages between the chronotype and work arrangements follows, and an overview of sleep disorders and circadian rhythm disorders that may influence our everyday life and work arrangements is provided. The thesis provides an overview of pulse oximetry and its technical aspects, as pulse oximetry is an important channel in most diagnostic methods to evaluate hypoxaemia and SDB. The aim, data, methods and key results from the studies underlying the doctoral thesis are discussed along with implications for practice and policy suggestions.

## Abbreviations

| | |
|---|---|
| AASM | American Academy of Sleep Medicine |
| AHI | apnea-hypopnea index |
| ASPS | advanced sleep phase syndrome |
| BMI | body mass index |
| DSPS | delayed sleep phase syndrome |
| EDS | excessive daytime sleepiness |
| EEG | electroencephalography |
| EHIS | Estonian nation-wide Health Information System |
| EMG | electromyography |
| EOG | electrooculography |
| ESS | Epworth Sleepiness Scale |
| FRD | free-running circadian disorder |
| Hb | deoxygenated hemoglobin |
| HbO | oxygenated hemoglobin |
| HC | Health Certificate |
| ICSD | International Classification of Sleep Disorders |
| ISWS | irregular sleep/wake syndrome |
| JLD | jet lag disorder |
| LEDs | light emitting diodes |
| MCTQ | Munich Chronotype Questionnaire |
| MEQ (meq) | Morningness-Eveningness Questionnaire |
| MSLT | Multiple Sleep Latency Test |
| MSFWe | mid-sleep on weekends |
| MWT | Maintenance of Wakefulness Test |
| NREM | non-rapid eye movement sleep |
| ODI | oxyhemoglobin desaturation index (i.e. oxygen desaturation index) |
| OLS | ordinary least squares |
| OSA | obstructive sleep apnea |
| PSG | polysomnography |
| REM | rapid-eye movement sleep |
| R&D | research and development |
| $SaO_2$ | arterial oxygen saturation |
| SD | standard deviation |
| SEM | structural equation modelling |
| SDB | sleep disordered breathing |
| $SO_2$ | oxygen saturation |
| $SpO_2$ | peripheral oxygen saturation |
| SRBD | sleep-related breathing disorder |
| SWD | shift-work disorder |

## Terms

| | |
|---|---|
| Apnea | The cessation of breathing |
| Apnea-hypopnea index | Number of apnea and hypopnea events per hour during sleep |
| Chronotype | A feature that characterises an individual's daily activity period preference with preferred creative time |
| Eveningness | The characteristic of being most active and alert during the evening; being a “night owl” or “evening person” |
| Morningness | The characteristic of being most active and alert during the morning; being a “lark” or a “morning person” |
| Oxygen desaturation | Decrease in oxyhemoglobin saturation; mainly due to an apnea or hypopnea; a measure of severity of respiratory failure |
| Oxygen saturation | Blood oxygen level; share of oxygen-saturated hemoglobin out of total hemoglobin (saturated plus unsaturated) in the blood |

# 1 Background and Literature

## 1.1 Sleep Regulation and Physiology

Our knowledge of sleep has advanced considerably during the past centuries. Sleep has restorative and modulating effects (Horne, 1998), which are important, for example, for growing and immune function, as well as for glucose level and cardiovascular control (van Cauter et al., 2008).

The implications of sleep for memory and cognitive function have attracted considerable research attention. Restrictions to sleep may bring along dysfunction of memory (Strickgold, 1998; Gais and Born, 2004). Inadequate quality of sleep and deficient sleep time may reduce concentration ability and cognition (van Dongen et al., 2003). In addition, sleep deprivation is one of the largest epidemic conditions in industrialised nations (Hillman and Lack, 2013).

The sleep and wake cycle is regulated by two opposing processes, circadian rhythm (known as process C) and homeostatic drive to sleep (known as process S). The neurologist von Economo described the regulating regions of sleep and wakefulness of the brain in his work on encephalitis lethargica in 1916 (Triarhou, 2006). The circadian rhythm is set in the hypothalamus through the suprachiasmatic nucleus that regulates the sleep-wake cycle (Saper et al., 2005). Sleep is highly determined by hypothalamic activity, γ-aminobutyric acid (GABA) and galanin (Steiger and Holsboer, 1997). Light enters the body through the retina and the suprachiasmatic nucleus work is synchronised with melatonin, melanopsin and cryptochrome receptors (Nakamura et al., 2011). The suprachiasmatic nucleus projects melatonin to the pineal gland, which promotes sleep. Light inhibits the release of melatonin from the pineal gland and thus affects the circadian cycle. However, the homeostatic process leads to somnolence, and it depends on sleep and wake regimen (Borbely, 1982; Borbely, 2009; Bassetti et al., 2014). Both the homeostatic and circadian regulation of sleep are important for daily functioning and safety, as well as for working capacity. Deterioration of the homeostatic regulation of sleep leads to a decrease in performance, judgment and alertness (Williamson et al., 2011).

A special form of sleep is microsleep. Microsleep is characterised by a short episode of mild sleep. Microsleep can occur in all people, especially during monotonous situations during the day.

## 1.2 Chronotype and Sleep

Human sleep and wakefulness are divided into a 24-hour period and controlled by biological rhythms. People are active during daytime, and at night time they are less active, because night hours are necessary for rest. Nathaniel Kleitman (born 1939) was the first to summarise the existing knowledge of sleep, and propose the basic sleep and wakefulness cycle (Kryger et al., 2014). Timing and total amount of sleep are determined by several factors, including environmental factors, endogenous circadian rhythms and time awake. Chronotype is individual and can be divided into eveningness (delayed sleep period) – approximately 22% of the population, morningness (advanced sleep period) – approximately 24%, and neither-type – approximately 54% (Adan and Almirall, 1991 and Randler, 2013). Recently it has been discovered that circadian rhythms have a genetic background (Kalmbach et al., 2017; reference should be made to 2017 Nobel Prize winners J. Hall, M. Rosbash and M. Young), and various personal and environmental features may also play a role in chronotype formation (Kerkhof, 1985; Adan et al., 2012). Roenneberg et al. (2007) found that endogenous regulation of biological clock is different for morning- and evening-types. Lack et al. (2009) have found that evening-types tend to wake up 3 hours after morning-type people and evening-time people go to bed around two hours later than morning-types. The same was confirmed by Horne and Östberg (1976) who demonstrated earlier peak hours of morning-types. The sleep-wake rhythm correlates with changes in melatonin and cortisol levels (Zavada et al., 2005), while Gigertini et al. (1999) have identified a link between melatonin and circadian rhythm. Roenneberg et al. (2004) studied a large cohort with objectively measured activity and rest and found that sleep timing and duration are generally independent but depending on the chronotype, some people sleep longer on weekends. In addition, chronotype is both age (Roenneberg et al., 2004) and gender dependent (Roenneberg et al., 2007). Cross-sectional studies showed that chronotype changes towards a morningness type orientation with advancing age (Monk and Buysse, 2014). Another population-based study among adults in Finland showed that the proportion of early chronotypes increased with age (Merikanto et al., 2015). Fisher et al. (2017) in their twelve-year study conducted in the USA found that men are usually later chronotypes than women before the age of 40. For non-standard types, either morningness or “lark” and eveningness or “night owl”, it is more difficult to adapt to daily social and working life. Evening types are more prone to psychological and psychosomatic disorders (Randler, 2008) and depression (Merikanto et al., 2013). Keeping the sleep time of an individual in alignment with chronotype can therefore potentially reduce safety and health risks.

## 1.3 Chronotype and Work

As society evolves, more and more people are working at inappropriate times for their sleep and health. According to a survey by Alterman et al. (2013), about 30% of all employees are engaged in shift work. Various studies (Megdal et al., 2005; Folkard et al., 2005; Gan et al., 2015; Vetter et al., 2015 and 2016) associate unusual work schedules with advanced health and safety risks. Another study (Vettel et al., 2015) investigated the individual need for sleep and daily rhythms of workers; they found some positive effects of individualisation of working schedules. Gender, age, and chronotype characteristics may also play a role in individualising working time (Fisher et al., 2017). Roenneberg et al. (2012) and Fisher et al. (2017) suggest that young adolescents are primarily evening-types while people over 40 can be both morning- and evening-types **(Figure 1.).** Some studies have shown (Sack et al., 1992; Morgenthaler et al., 2007) that young people are more likely to have delayed sleep phase syndrome and elderly people have often different sleep disorders. It can be assumed that people of different ages suffer from different types of sleep disorders, such as circadian rhythm disturbances in adolescents. This may be the reason why people of different ages have different working time preferences.

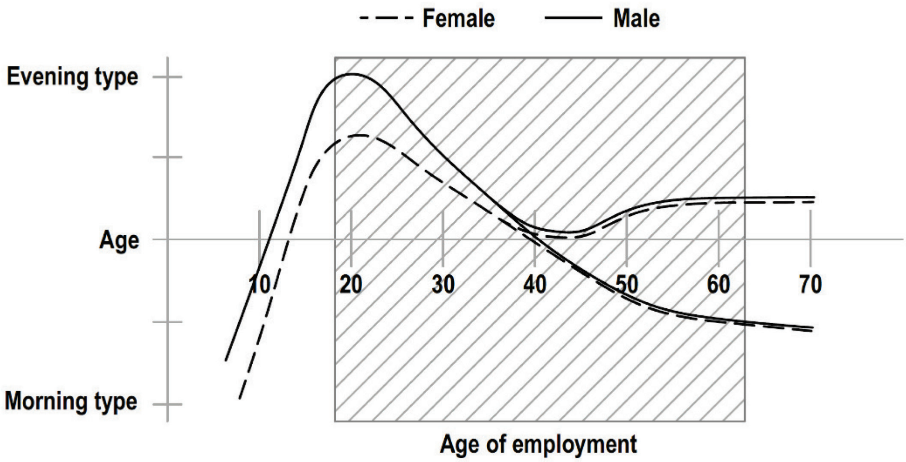



***Figure 1***. *Distribution of chronotypes by age, gender and years of employment. Author`s additions to Roenneberg (2012) and Fisher et al. (2017).*

Juda et al. (2013) found that during the working week, the late chronotypes accumulate significant sleep debt, which they offset on weekends by prolonged sleep. Certainly, the timing of sleep has changed during industrialisation for various reasons. The quality of sleep affects a person as a whole, from learning, memory, alertness and performance to quality of life.

Employability represents the precondition for employment of individuals, and different jobs require different demands (Chan, 2000). Some studies (e.g. Pulakos et al., 2000; Hall, 2002; Fugate et al., 2004) suggest that employees need to adapt to a changing environment in a competitive labour market and have to cope with the changes that are taking place all the time. Middle-aged workers also need to adjust their sleeping habits if they are to be more competitive in the workplace (Carrier et al., 1997; Taillard et al., 1999). Kerkhof and von Dongen (1996) have found that time preferences and behaviour of morning- and evening-types result from phase differences in the endogenous circadian clock. Evening-type employees sleep less than the morning-types (Ishihara et al., 1988) and they are more prone to have different health problems (Paine et al., 2006).

Past research has documented the relationship between sleep duration and genetics (Utge et al., 2011; Goel, 2017) and work (Antillon et al., 2014; Ásgeirsdóttir and Ólafsson, 2015). Some studies associate sleep with income levels (Biddle and Hamermesh, 1990; Grandner, 2010; Patel et al., 2010; Ásgeirsdóttir and Zoega, 2011; Sedigh et al., 2017). Differences in the employment options of different chronotypes have not been studied before.

Workers' sleep and quality of life are affected by working time and workplace location and other aspects of work organisation. The traditional "nine-to-five" work schedule is unlikely to fit the heterogeneous qualities of "normal" employees. Caldwell and O'Reilly (1990) emphasise the importance of individual attributes and work environment in improving the performance of their research. It is believed that flexible working hours are an important factor allowing employees to adjust their working hours to their personal preferences and to work at the time when they feel most productive. Golembiewski and Proehl (1978) refer to the positive impact of flexible working hours in controlling work and personal life in the analysis of working time studies. Golden et al.

(2013) show that flexible working time arrangements are associated with increased happiness.

The main advantage of flexible working hours is that it allows employees to count on their individual circadian rhythms associated with sleep timing preferences. For example, morning-type people tend to go to bed early as well as to wake up early, and they are more alert at the beginning of the day. But people in the evening style prefer to go to bed later and also wake up later, and be more alert in the evening. Phase disturbances of circadian rhythmic functions may be large ranging from 2 to 12 hours between morning types and evening types (Roenneberg, 2012).

An inappropriate work schedule that runs counter to a 24-hour clock can have an adverse effect on the employee. If the individual sleep-wake cycle is not synchronised with the individual circadian rhythms, the risk of multiple health risks increases (Veatch et al., 2017). Juda et al. (2013) among others have studied the chronotype and shift work connections. They confirmed that during night shifts, morning-type workers had reduced sleep duration, severe social jet breakdown, and increased sleep disorder. Similar symptoms were also observed for evening-type workers in an early shift.

However, greater control over working time can be positive on workers' sleep and health. Takahashi et al. (2011) investigated the relationship between working time control and fatigue, sleep disorders and symptoms of depression in daytime as well as shift workers. They discovered that greater working time control, measured both for working hours and holidays, was associated with a reduction in incomplete recovery, symptoms of insomnia (in men only), daytime sleepiness and symptoms of depression.

The impact of working time weariness on employee health initiated by the company was investigated by Moen et al. (2011). They found that working time flexibility had a positive impact on employee health behaviour, including workers sleeping for almost an hour longer and being in general less sick. Mellner et al. (2016) found that work and sleep time flexibility improves the psychological health of employees.

## 1.4 Sleep Disorders

Good sleep is crucial to employees' day-to-day well-being, work capacity and mood. Most people have experienced short-term sleep disturbances during their lives, for example due to stress or grief. However, sleep disorders can last for a longer period of time, interfering with both daytime coping and general health, whereas the sleep disorder may not be perceived by the person suffering from it. Several sleep disorders can lead to daytime sleepiness, fatigue, irritability, deterioration of attention and memory and cause performance impairment (Bassetti et al., 2014).

On a practical note, while planning this study, the author could not find any validated guidelines in Estonia for the initial diagnosis of various sleep disorders that occur at the same time. Due to the limited possibility of screening for sleep disorders, the author initiated the preparation of a diagnostic guideline "First-line diagnostic guidelines of sleep disorders among adults" in Estonia, which was completed in 2019. For example, an increased motor vehicle accidental risk is mainly linked to EDS and work disability. Several sleep disorders are characterised by sleepiness, lack of energy and impaired night sleep (Bassetti et al., 2014).

The International Classification of Sleep Disorders (ICSD-3) recommends that sleep disorders be classified as follows: insomnia, circadian rhythm disorders, sleep-related breathing disorders, hypersomnia, parasomnias, and sleep-related movement disorders.

All sleep disorders are often underdiagnosed. This thesis is primarily focussed on circadian rhythm disorders.

Circadian rhythmicity regulates different physiological processes, like body temperature and levels of different hormones (Sack et al., 2007, part I). These processes differ by age, gender and morningness-eveningness type. As chronotype is not a sleep and wakefulness disorder, the expected maximum creative time of people with different chronotypes and sleep and wakefulness disorders are presented in **Figure 2**. Morning types prefer go to bed earlier and also experience earlier time of the day in alertness (Sack et al., 2007; Hofstra and de Weerd, 2008). Recent studies (also in animals) show specific differences between genotypes, including PER1, PER2 and PER3 genes, the CLOCK gene, and cryptochrome genes (CRY1 and CRY2) that lead to abnormalities in circadian rhythmicity (Viola et al., 2007; Dijk and Archer, 2009; Wulff et al., 2009). No routine genetic testing is currently available to general practice to establish these disorders (Sack et al., 1992; Morgenthaler et al., 2007).

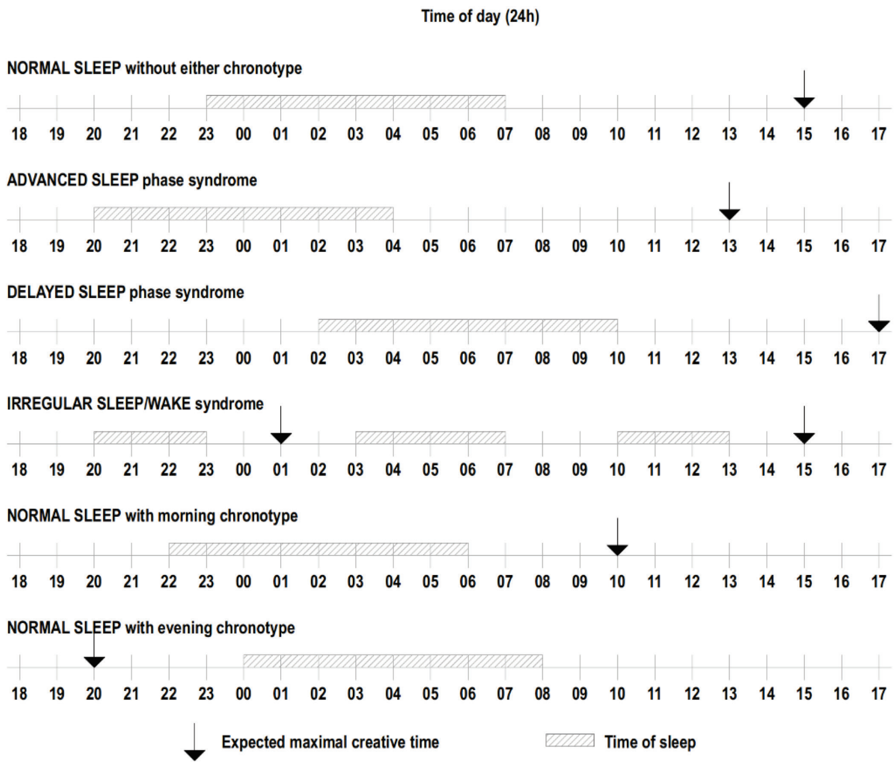



***Figure 2.*** *Schematic representation of normal sleep in different chronotypes and different types of circadian rhythm disorders with their hypothetical peak creative time. Adapted from Lu et al. (2006).*

Start of the use of artificial light changed the lifestyle due to disruption of natural cycles of light and darkness. Several studies show that changes in the timing of internal processes may cause diseases. For example, a study that used mice suggests that manipulation of meal timing may cause obesity and metabolic diseases (Arble et al., 2009; Hatori et al., 2012). A study on hamsters shows that disruption of circadian organisation can lead to cardiomyopathy (Martino et al., 2008). Another study about sleep-disrupted mice demonstrated increased development of inflammation and colitis (Tang et al., 2009). Reproductive abnormalities have been described in mice, including irregularities in oestrous cycles and failures in pregnancy (Miller et al., 2004; Summa et al., 2012). Levi et al. (2010) concluded that shift work is probably carcinogenic to humans.

The International Classification of Sleep Disorders (ICSD-3) recommends that circadian rhythm disorders be classified as follows:

- **Delayed sleep phase syndrome** (DSPS), or "night owl" syndrome, common in approximately 7% of young adults and adolescents (Sack et al., 1992; Morgenthaler et al., 2007). Typically, the delay sleep and waking time is 3-6 hours compared to normal sleep time. A person is usually sleepy and ready to go to bed from 2 am to 6 am and wakes up at 10 am or later.
- **Advanced sleep phase syndrome** (ASPS), or so-called "lark" syndrome is characterised by the onset of sleep and waking up 3 hours earlier than normal sleep time. Usually a person is sleepy and ready to sleep as early as 7 pm - 9 pm and wakes up at 5 am or earlier. The syndrome is rare, with approximately 1% of middle-aged adults being subject to ASPS (Hofstra and Weerd, 2008).
- **Free-running circadian disorder** (FRD) is also called non-24-hour sleep-wake disorder. FRD occurs, for example, in psychiatric disorders, with both insomnia and somnolence, and is widespread among the blind (Skene and Arendt, 2007).
- **Irregular sleep/wake syndrome** (ISWS) is a rare disease characterised by repeated episodes of sleep during the day with no complete night-time sleep. This syndrome is common in elderly patients with neurological disorders.
- **Shift-work disorder** (SWD) is a work schedule driven disorder characterised by insomnia and sleepiness. SWD is common in every society where the service or production sector of the economy needs to be maintained 24 hours a day. Many individuals cope with shift work. The problem is increasing among employees aged over 50 years who have a history of some sleep disorder or alcohol abuse.
- **Jet lag disorder** (JLD) may occur in a person while traveling at least two time zones, resulting in sleep disorders, fatigue, reduced concentration and attention, loss of appetite, or digestive disorders (Sack et al., 2007, Part I).

The author of the thesis is convinced that it is very difficult to clearly distinguish between morning-type and ASPS as well as evening-type and DSPS by studying sleep more precisely, leaving some inherent circadian rhythm patterns of individuals potentially disregarded if those do not fall under specific sleep disorders. Moreover, the occurrence of circadian rhythm disorders and their overall impact on health and social life has been considered scarcely to date.

## 1.5 Assessment of Chronotype, Sleep and Wakefulness

The evaluation of chronotype, sleep and wakefulness disorders and various sleep disorders by subjective scales and evidence based studies should be interpreted in combination. Conducting questionnaires and collecting specific survey data can be organised at home as well as in a medical facility.

Chronotypes can be investigated using straightforward questionnaires like the **Horne-Ostberg morningness-eveningness questionnaire** (MEQ) (Horne and Ostberg, 1976) and the **Munich Chronotype Questionnaire** (MCTQ) that differentiate timing of the daily activities during workdays versus free days (Roenneberg et al., 2007). The author of the thesis notes that these questionnaires mainly take into account sleep time in a week and some psychological factors (e.g., the occurrence of depression), but do not take into account the employee's working time preferences and the maximum peak of the expected (creative) work time. **The Circadian Type (Inventory) Questionnaire** by Flokard (1987) was originally developed to find people adaptable to shift work, but is not used today due to a lack of psychometric measurements (Greenwood, 1995). Roenneberg et al. (2003) developed a simple questionnaire MCTQ to assess a chronotype and validated this to MEQ (Zavada et al., 2005).

There are several scales and questionnaires for diagnosing sleep disorders. The **Epworth Sleepiness Scale** (ESS) is often used for evaluation of EDS. Higher scores indicate a higher probability of occurrence of EDS. The **Multiple Sleep Latency Test** (MSLT) is used for measurements of sleepiness using EEG electrodes. The **Maintenance of Wakefulness Test** (MWT) is used for quantitative assessment and objective documentation of daytime sleepiness. Both of the latter tests are performed in a sleep lab. People with excessive daytime sleepiness tend to get drowsy during the daytime in unsuitable situations such as driving or monotonous computer work.

There are several diagnostic techniques for assessing sleep disorders. Historically, the most commonly used gold standard for diagnosing sleep disorders was overnight PSG (Epstein et al., 2009), which requires monitoring of oxyhemoglobin saturation among other channels (Malhotra et al., 2018). Alternative portable devices have been developed for more efficient use of healthcare resources and nowadays different polygraphies take the most important place in the diagnosis of SDB (Masa Jiménez et al., 2007). Several devices are currently available to be worn at home by patients during sleep. Sleep monitoring devices are classified according to completeness of the signals recorded and presence of technician overnight into different types (Collop et al., 2007).

Looking for the most appropriate way for a sleep study device under this thesis, the author compiled a comparison of various devices used in sleep studies according to the number of channels, main channels, less frequently used channels (e.g. body position or leg movement) and needs for personnel involvement. As a result, a common channel for diagnosing all SDB – $SpO_2$ – was identified, which has proven, for example, to be one of the main channels for recent studies in pulmonary artery tonometry (PAT). PAT is one of the newest portable devices used to diagnose sleep apnea in combination with pulse rate, oximetry ($SpO_2$) and actigraphy (Penzel et al., 2010; Pittman et al., 2004), while Hedner et al. (2011) found its moderate agreement with standard PSG. Pulse oximetry is the most important channel for the diagnosis of SDB, as most sleep-related breathing problems are accompanied by some change in the level of oxyhemoglobin. The author of the thesis classified sleep studies into five levels of decreasing complexity, and found that pulse oximetry ($SpO_2$) is included in all types of those investigations. A survey among physicians working in academic sleep study centres in 22 European countries revealed that respiratory polygraphy (e.g. cardiorespiratory polygraphy) was used in more than 70% of those for home study, while pulse oximetry was found to be used for diagnosis of OSA in 5 countries (Arnardottir et al., 2016). Similar information is reported by the Canadian Thoracic Society (Blackman et al., 2010; Fleetham et al., 2011).

Pulse oximeters are reliable and robust devices available for use in hospital and at home for measuring and monitoring a person's oxygen saturation ($SO_2$), also recommended by the AASM guidelines (Redline et al., 2007). Peripheral oxygen saturation ($SpO_2$), as determined by pulse oximeter, is well correlated with oxygen saturation ($SaO_2$), as determined by arterial blood analysis (Penneys, 1952). The device is useful for patients with cardiac and respiratory problems (Schlosshan and Elliott, 2004; Fu et al., 2004; Ewer et al., 2011; Chung et al., 2012; Amalakanti and Pentakota, 2016). Pulse oximetry was developed in 1972 (Severinghaus and Honda, 1987), and the device was commercialised by Biox in 1980 (Kelleher et al., 1989). Pulse oximetry is inexpensive yet safe, convenient and non-invasive (Norfleet and Watson, 1985).

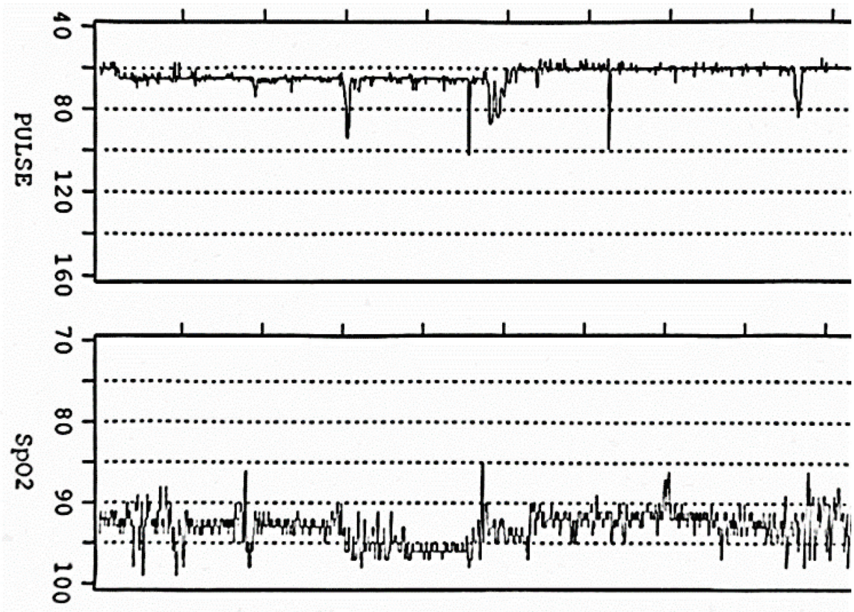
Before the home study, a person is informed by a healthcare professional how to use the device at home; the person performs the investigation at home and brings the device back to the hospital. There are special computer programs available for analysis and reporting of the results. Pulse oximeter is typically placed on the finger, more seldom on the ear, toe or across a foot. The study measures the absorption of transmitted light by the tissue (Herbert et al., 2012), and results displayed on the pulse oximetry monitor pulse rate and oxygen saturation.

Pulse oximetry works based on the optical absorption of hemoglobin. Deoxyhemoglobin (Hb) is characterised by red-light absorption (wavelength 600-750 nm), and oxyhemoglobin ($HbO_2$) works on the infrared spectrum (850-1000 nm). There is no minimum technical specification or standard criteria specified (Berry et al., 2018). The sensitivity and specificity of pulse oximetry at different cut-points can range (Chiner et al., 1999). Pulse oximetry can show false negatives, especially in young patients, as well as false positives in patients having different comorbidities (Zamarron et al., 2003; Epstein et al., 2009).

## 1.6 False Negative Results of Sleep Studies in Practice

Until today, the exact reasons for the wish to conceal with sleep related information by some persons are not known. However, for example, from the experience of various sleep studies at the Department of Pulmonology at North Estonia Medical Centre since 2002 (approx. 700 investigations per year), several persons have given the pulse oximetry device for home study to a third person. For example, the author of the thesis has found evidence of sleep studies where the pulse rate curve shows additional cardiac stimulation but the patient does not have artificial cardiac pacemaker really **(Photo 1; A and B)**. These investigations were performed by a 41-year man in North Estonia Medical Centre in January 2013.

***A)*** *Investigation performed by a person having artificial cardiac pacemaker programmed at the pulse rate of 60 per minute*




***B)*** *Investigation performed by the same person after scoring of sleep studies where he was informed of not really having an artificial cardiac pacemaker*

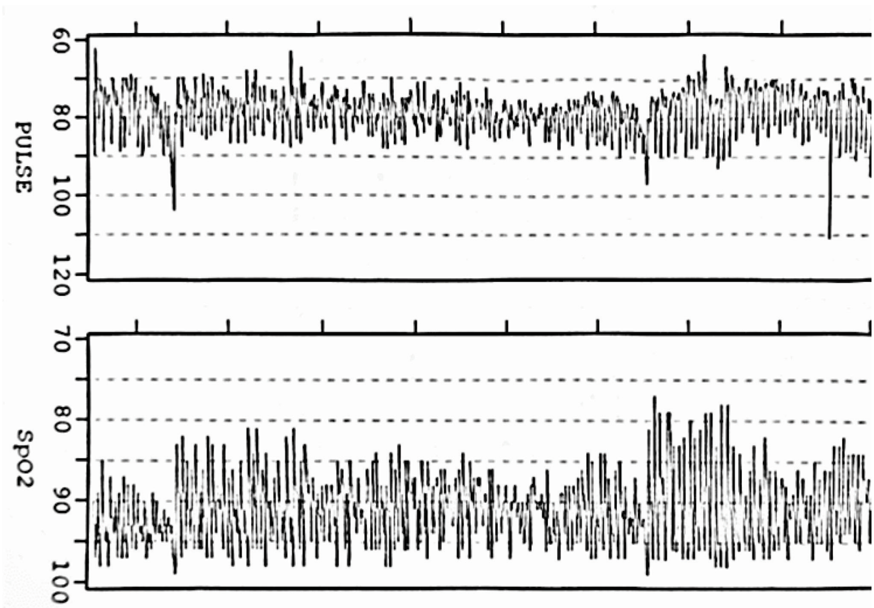
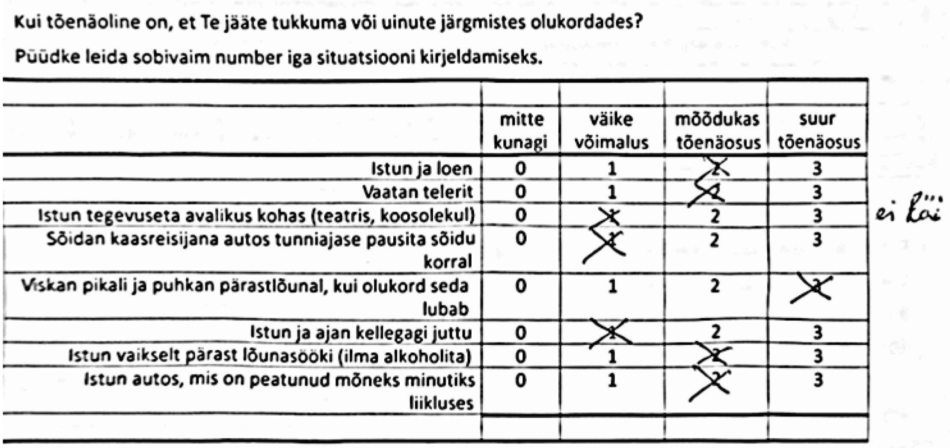



***Photo 1.*** *Example of a pulse oximetry performed by different persons during home studies of a 41-year male at North Estonia Medical Centre in January 2013. Photos by Erve Sõõru.*

Among other sleep disorders, in some cases, untreated obstructive sleep apnea has been found to cause excessive daytime somnolence and is therefore a considerable source of risk for road accidents (Bonsignore et al., 2014). The number of sleep studies increased in general, following the implementation of the European Union (EU) Driving License Directive 2014 (Commission Directive 2014/85 / EU), with a greater need for cheaper and home-based surveys. It came as a surprise to many drivers who could not suspect obstructive sleep apnea. Under that EU Directive, drivers were afraid of losing their license (Ghosh et al., 2016) and false negative results of the study with incorrect decisions from medical personnel. As discussed earlier, there is practical evidence that some people have given the device for home use sleep study for a third person, which is also true for giving false negative answers when filling the questionnaires of sleepiness **(Photo 2)**.

***A)*** *ESS (in Estonian) filled by a driver in 2012, before the EU Directive on Driving Licenses*

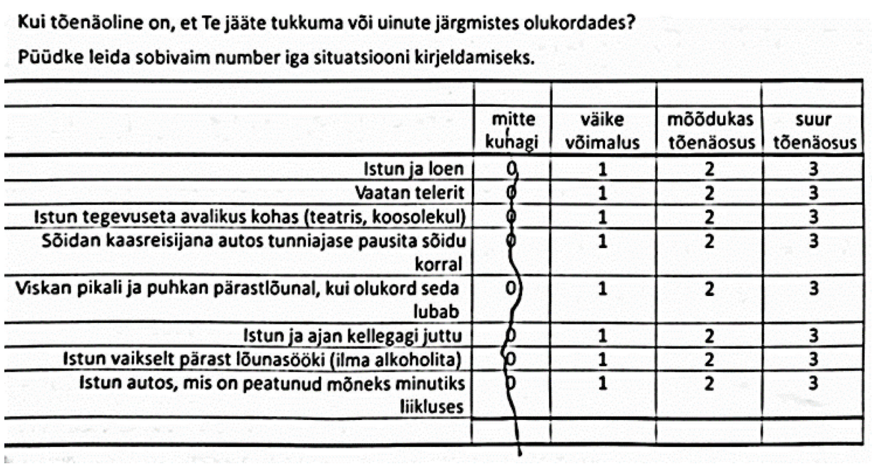


**Kui tõenäoline on, et Te jääte tukkuma või uinute järgmistes olukordades?**

**Püüdke leida sobivaim number iga situatsiooni kirjeldamiseks.**

| | mitte kunagi | väike võimalus | mõõdukas tõenäosus | suur tõenäosus |
|---|---|---|---|---|
| Istun ja loen | 0 | 1 | X | 3 |
| Vaatan telerit | 0 | 1 | X | 3 |
| Istun tegevuseta avalikus kohas (teatris, koosolekul) | 0 | X | 2 | 3 |
| Sõidan kaasreisijana autos tunniajase pausita sõidu korral | 0 | X | 2 | 3 |
| Viskan pikali ja puhkan pärastlõunal, kui olukord seda lubab | 0 | 1 | 2 | X |
| Istun ja ajan kellegagi juttu | 0 | X | 2 | 3 |
| Istun vaikselt pärast lõunasööki (ilma alkoholita) | 0 | 1 | X | 3 |
| Istun autos, mis on peatunud mõneks minutiks liikluses | 0 | 1 | X | 3 |

***B)*** *ESS (in Estonian) filled by a driver in 2016, in fear of losing the license as per the EU Directive on Driving Licenses*



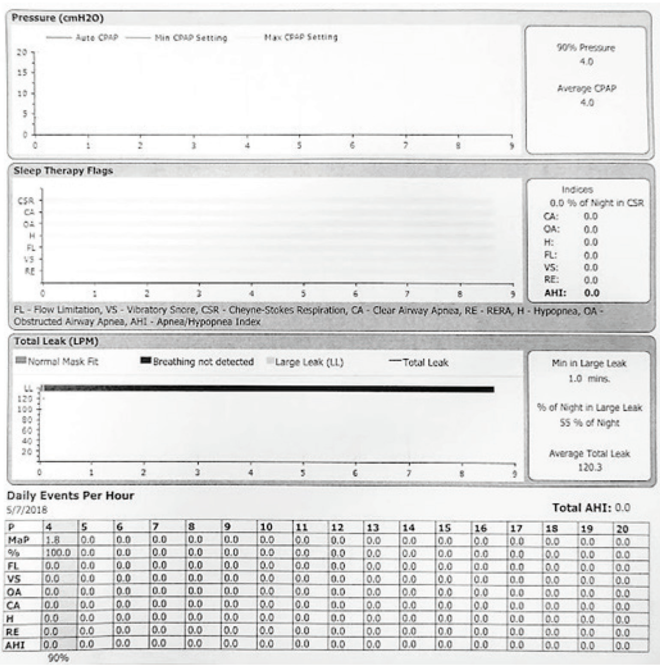
**Kui tõenäoline on, et Te jääte tukkuma või uinute järgmistes olukordades?**

**Püüdke leida sobivaim number iga situatsiooni kirjeldamiseks.**

| | mitte kunagi | väike võimalus | mõõdukas tõenäosus | suur tõenäosus |
|---|---|---|---|---|
| Istun ja loen | 0 | 1 | 2 | 3 |
| Vaatan telerit | 0 | 1 | 2 | 3 |
| Istun tegevuseta avalikus kohas (teatris, koosolekul) | 0 | 1 | 2 | 3 |
| Sõidan kaasreisijana autos tunniajase pausita sõidu korral | 0 | 1 | 2 | 3 |
| Viskan pikali ja puhkan pärastlõunal, kui olukord seda lubab | 0 | 1 | 2 | 3 |
| Istun ja ajan kellegagi juttu | 0 | 1 | 2 | 3 |
| Istun vaikselt pärast lõunasööki (ilma alkoholita) | 0 | 1 | 2 | 3 |
| Istun autos, mis on peatunud mõneks minutiks liikluses | 0 | 1 | 2 | 3 |

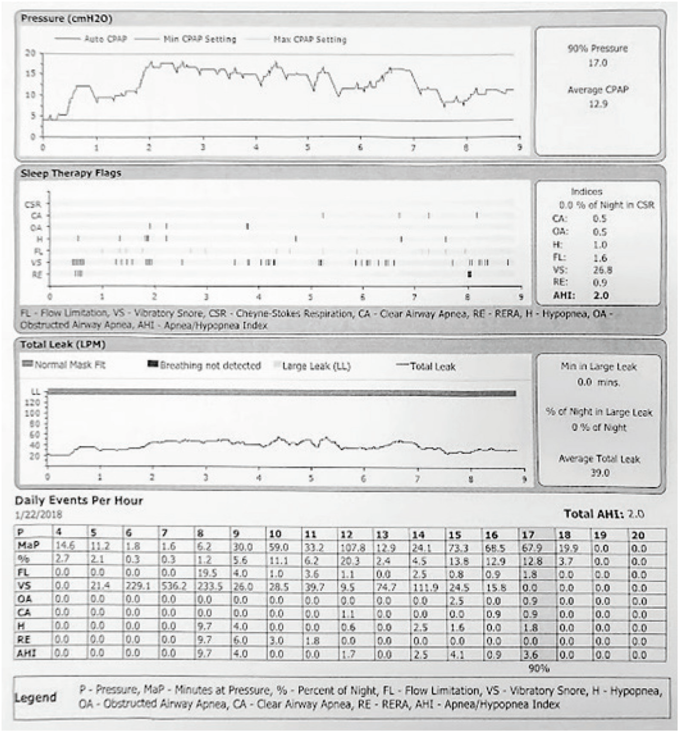
***Photo 2.*** *The Epworth Sleepiness Scale (ESS), a self-administered questionnaire with the higher score showing a person's average sleep propensity in daily life or their daytime sleepiness. Photos by Erve Sõõru.*

The author also found in practice that in some cases patients did not want to be treated. For example, after introducing the treatment method to a patient, he was interested in the treatment and was ready to use the positive pressure device at home during the test period. Surprisingly, during the next visit, the nurse discovered that the patient had not used the positive pressure device at home during the test period. **Photo 3** demonstrates the comparison of **(A)** patient investigation when the patient did not sleep with the device on (the device was fixed with the mask to the pillow for nine hours and breathing was not detected) and **(B)** investigation results in the same patient after careful discussion with the patient, where Pressure, Sleep Therapy Flags, Normal Mask Fit and Results are available. These investigations were performed by a 34-year male in North Estonia Medical Centre in 2017.




**A)**

B)




| P | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MaP | 14.6 | 11.2 | 1.8 | 1.6 | 6.2 | 30.0 | 59.0 | 33.2 | 107.8 | 12.9 | 24.1 | 73.3 | 68.5 | 67.9 | 19.9 | 0.0 | 0.0 |
| % | 2.7 | 2.1 | 0.3 | 0.3 | 1.2 | 5.6 | 11.1 | 6.2 | 20.3 | 2.4 | 4.5 | 13.8 | 12.9 | 12.8 | 3.7 | 0.0 | 0.0 |
| FL | 0.0 | 0.0 | 0.0 | 0.0 | 19.5 | 4.0 | 1.0 | 3.6 | 1.1 | 0.0 | 2.5 | 0.8 | 0.9 | 1.8 | 0.0 | 0.0 | 0.0 |
| VS | 0.0 | 21.4 | 229.1 | 536.2 | 233.5 | 26.0 | 28.5 | 39.7 | 9.5 | 74.7 | 111.9 | 24.5 | 15.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| OA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.5 | 0.0 | 0.9 | 0.0 | 0.0 | 0.0 |
| CA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 0.0 | 0.0 | 0.9 | 0.9 | 0.0 | 0.0 | 0.0 |
| H | 0.0 | 0.0 | 0.0 | 0.0 | 9.7 | 4.0 | 0.0 | 0.0 | 0.6 | 0.0 | 2.5 | 1.6 | 0.0 | 1.8 | 0.0 | 0.0 | 0.0 |
| RE | 0.0 | 0.0 | 0.0 | 0.0 | 9.7 | 6.0 | 3.0 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| AHI | 0.0 | 0.0 | 0.0 | 0.0 | 9.7 | 4.0 | 0.0 | 0.0 | 1.7 | 0.0 | 2.5 | 4.1 | 0.9 | 3.6 | 0.0 | 0.0 | 0.0 |

***Photo 3.*** *Treatment protocols of obstructive sleep apnea with a continuous positive airway pressure device. Photos by Erve Sõõru.*

No previous studies have addressed the manipulation of identification sensors during sleep studies. There are no devices to identify the patient during sleep studies and the invention presented in this thesis aims to solve that problem.

## 1.7 Aim of the Study

Recognising the role of sleep for health, wellbeing and socio-economic performance has increased with the development of sleep medicine. Nowadays the diagnosis and treatment of sleep disorders are receiving increasing attention, though they can be underdiagnosed. In this developing field of research, this thesis is focussed on the relationship between sleep disorders/habits and circadian rhythm disorders/habits and work. Human chronotypes are normal variants that have been studied in the last few decades only, leading to new evidence based knowledge about the origins of “lark” and “nightowl” behaviours. Considering that a large share of people are distinctly morning-type or evening-type, in addition to those who are of neither type, there may be a considerable mismatch between the sleep preferences deriving from chronotype and work arrangements, like the timing of work. So far, the distinction between chronotypes has been largely based on the preferred time of awakening on weekdays and weekends, and vast differences have been identified in individual morningness-eveningness types. The usual operating hours in the society are, however, 9 am-5 pm that may not be in alignment with the preferences of a large share of the population, in particular the evening types. More and more people are working at times when they are not productive and sleep disorders affect general health. This is particularly relevant for knowledge employees who have to use their creative potential to perform their work.

One of the areas where there is a gap of knowledge is - which types of creative knowledge workers suffer more from the consequences of their work organisation in terms of their sleep needs. The traditional daily work schedule of nine to five may not be suitable for all, and if employees follow those standard schedules, their sleeping patterns and daily rhythms may be adversely impacted. Also, non-standard work arrangements may have their impact on sleep.

There is a lack of studies where sleep and work arrangements have been investigated together. Chronotype is age and gender dependent, and genetics of sleep seems to be a promising field. Identification of the spillover effects of chronotype on the socio-economic behaviour and performance is therefore an interesting path of research to complement the advances in sleep research to other disciplines.

Another aspect in the sleep-work connection that warrants study is that morning and evening types might not have similar work opportunities given potential restrictions to employment options deriving from the timing of work. This, in combination with work related distractions to sleep, may have an adverse effect on efficient utilisation of people's creativity, their work performance and health. Evening-type people might feel that their sleep is disturbed by the timing of their work. Moreover, evening-type people may feel that their natural sleep patterns set constraints on their employment opportunities. It is conceivable that it may be impossible or difficult for a person to adjust their chronotype to match the normal working hours prescribed by the employer, which in turn may reduce that person's job opportunities. It can be taken into account that if an employer does not allow flexible working hours and sleeping arrangements, a talented evening person may not want a job which requires primarily a morning time readiness to perform duties.

The literature review above suggests one more area in the sleep-work linkages where further research is needed – the use of diagnostic tools in identifying sleep problems that may hinder work performance. There are numerous diagnostic methods available to diagnose sleep disorders (Collop et al., 2007), including diagnostics of SDB. Both, the sleepiness and hypoxaemia might contribute to cognitive deficits (Englemann et al., 2000). Out of the different sensors for the evaluation of sleep disorders, the most important one for the evaluation of respiratory events in sleep studies is pulse oximetry, which allows us to identify hypoxaemia, sleep apnea and other SDB, such as chronic obstructive pulmonary disease (Verbraecken, 2012). Some of the occupations in which sleep related problems require closer attention are rescue workers and drivers. Wearable pulse oximeters enable sleep study at home during normal night sleep, but manipulation of the results has to be excluded. The need for personalisation of sleep research arose during practice where the research apparatus was given to someone else to conduct the study. The false negative effects of sleep studies are described in various studies. Improper diagnosis could result in inappropriate patient treatment or workability assessment. However, a method that would detect the use of sleep investigation tools by a third person during the home study period has not been available. Based on literature review, out of the diagnostic techniques for the assessment of sleep disorders, a pulse oximeter appears to be the most appropriate device for personalising examinations.

Based on the literature overview on sleep, chronotype, work arrangements and diagnostic techniques for the assessment of sleep disorders, the research presented in this doctoral thesis proceeds from setting the following research **hypotheses**:

1. In creative knowledge jobs, evening-type employees feel more intensely than morning-types that their sleep regimen is disturbed by their work.
2. In creative knowledge jobs, evening-type employees feel more intensely than morning-types that their sleep habits restrict their employment options.
3. In creative knowledge jobs, employees with longer sleeping hours feel more intensely than those with shorter sleeping hours that their sleep regimen is disturbed by their work.
4. In creative knowledge jobs, employees with longer sleeping hours feel more intensely than those with shorter sleeping hours that their sleep habits restrict their employment options.
5. In creative knowledge jobs, employees with fixed working arrangements feel more intensely than those with flexible working arrangements that their sleep regimen is disturbed by their work.
6. Pulse oximetry can be combined with person´s identification capabilities to identify if a wearable pulse oximetry device has been used by a third person during the study period.

**The aim of the thesis** is to:

1. Identify, based on a questionnaire survey among Estonian creative R&D employees, which types of creative knowledge employees suffer from the adverse effects on their sleep regimen caused by work arrangements, with special focus on the morningness-eveningness types and sleep duration of employees as well as the availability of flexible working options.
2. Identify, based on a questionnaire survey among Estonian creative R&D employees, which types of creative knowledge employees perceive restrictions that sleep habits set on the employment options, with special focus on the morningness-eveningness types and sleep duration of employees.
3. Invent a method and a device for unambiguous identification of a person who undergoes sleep studies with a pulse oximeter.

# 2 Data and Methodology

The studies underlying this thesis focus on linkages between sleep habits, chronotype, and work arrangements and opportunities among creative R&D employees. The research is based on survey data and provides a pilot study on constraints on employability and on work-related limitations to sleep that individuals of different morningness-eveningness preferences and with different sleep habits perceived under different work arrangements. Another element of the thesis is an invention of a new device for personalised pulse oximetry of a patient for the investigation of sleep disorders. The invention comprises a wearable pulse oximeter and sleep study sensors comprising a unit for identifying identity of the wearer of the pulse oximeter supplied for the patient for home use sleep study to identify if the device is used by any other person during the study period.

## 2.1 Study Design

The study **(Publication I and Publication II)** is based on an online survey including questions on work arrangements, work outcomes, sleepiness, sleep regimen, tiredness, health, and some socio-demographic characteristics. The respondents gave answers for their name, age, gender, education and work details. This research project was approved by the Tallinn Medical Research Ethics Committee on 9 February 2015 by decision No. 894 and informed consent was obtained from all the respondents. The research group performed the survey in 2015-2016, under two waves. The studies presented in this thesis are part of a broader research project that includes papers like Hazak et al. (2016; 2017; 2019), Virkebau and Hazak (2017) and Ruubel and Hazak (2018) using the same dataset.

The invention **(Publication III)** is a technical solution created by the research group for a novel device and a diagnostic method and a combination thereof. First of all, the applied problem was identified, the various technical options to fix the problem were considered thereafter, followed by the creation and description of a new technical solution, and its registration and protecting the application of invention.

## 2.2 Sample for the Study

The sample **(Publications I and II)** was compiled by other members of the research group from the Statistics Estonia data on research and development. At first, the aim was to reach an entire population of interest of creative R&D workers in the country, which is represented by the category “researchers” in the Statistics Estonia classification while excluding the categories “technicians” and “supporting staff”. 4,400 full-time working creative R&D employees are covered by the Statistics Estonia database in the category “researchers” in Estonia in 2010-2014. First, the research group excluded about 3,400 employees working in education and healthcare, and those employed at micro-size entities with fewer than fifteen creative knowledge employees from the population to be studied. The reason was the teaching schedules in educational entities, the procedures and appointments at medical entities, as well as the working practices at micro-size entities, where their work arrangements are quite specific and may distort the study of work, sleep, health and leisure time decisions that our project was targeted at. Therefore, approximately 1,000 creative R&D employees were eventually selected as targets for the study.

Those employees were working for 23 Estonian companies in both the private and public sectors, including researchers, product developers, IT developers and other creative R&D employees at private R&D companies, banks and technology and IT companies, and at public research institutes. All the 23 entities were invited for participation in the questionnaire survey, and 11 employers (48%) accepted the invitation. From those 11 organisations, we invited altogether 807 employees to participate, and 287 of them agreed. The survey was completed by 217 employees in at least one of the two waves. The overall response rate was 76% of all those who had agreed to participate.

Only 34 persons from 217 participants appeared in both the first and the second wave of the survey. The differences between the two waves in how sleep was perceived to restrict work options and how work was perceived to impact sleep by the recurring respondents were statistically insignificant. The data from both survey waves was pooled for the regression analysis and after that it was selected randomly which of the two responses from the 34 recurring participants to use. Additional eliminations were made from the sample as outlined in **Publications I and II**. The reasons were logical inconsistencies in the responses and if the respondent was identified from certain control questions incorporated in the survey questionnaire as not being sufficiently engaged in R&D for their employer.

The final sample consisted of 153 employees, which equals 53% of those who agreed to participate in the survey. The observations in the sample were allocated weights to match them with the population of interest for the employer's area of activity and the employee's gender.

## 2.3 Dependent and Explanatory Variables in the Study

The author of the thesis designed the sleep related elements of the questionnaire survey. Our research group used a Likert 1…5 scale response to the question "To what extent do you feel that your work is limiting or has limited your sleep regimen?" (*sleeplim*) as the target variable for the regression analysis in **Publication I. Publication II** addresses the question of how much employees feel that their chronotype sets constraints on their employment. The answer to the question "To what extent do you feel that your sleep cycle limits or has limited your work options?" on a Likert 1…5 scale gives the dependent variable *restriction* in the models presented in **Publication II**.

Explanatory variables are primarily derived from the previous literature. Based on Adan and Almirall (1991), the Reduced Morningness-Eveningness Questionnaire score (*meq*) captures the chronotype of the worker. Average sleep hours reflect actual daily sleep patterns. The key control variables incorporated for socio-demographic characteristics of the respondents are age, gender, whether they live alone, how many children younger than school age they have and their level of education, while the *phealth* variable controls the general health of the employee. The creative intensity desired for work is another explanatory variable and it seeks to capture the creative nature of the work that the employee prefers. Detailed description of the variables incorporated in the regression models is presented in **Publications I and II**.

## 2.4 Statistical Modelling Methods

Our research group compiled six alternative models to estimate the extent to which employees perceived that their sleep regimen was limited by work for the research in **Publication I**. These models help to gain insight into how sleep and work arrangements may be related to each other, as well as help for robustness testing. Models 1 and 2 in **Publication I** are ordinary least squares (OLS) continuous estimations of *sleeplim* and Models 3 and 4 in **Publication I** show the ordered probit maximum likelihood estimations of the ordered discrete categories of *sleeplim*. The ordered probit estimation gave a better descriptive power for the dependent variable compared to the OLS model, because the distribution of the dependent variable is skewed and non-normal. In addition, structural equation models (SEM, Models 5 and 6) were composed in order to take into account the selection patterns arising from certain types of employees opting for flexible working time and for positions with different creative intensity. The latter two three-dimensional models present *sleeplim* as the final stage dependent variable with the ordered probit estimates of *sleeplim* in the main equation, containing *flextime* and *creatime* as the endogenous selection variables among other explanatory variables. We used the cmp (Conditional Mixed Process) module of the Stata version 14 software by StataCorp (USA).

For the study in Paper II, our research team used ordinary least squares (OLS) estimations with *restriction* as a continuous variable (Models 1 and 2 in **Publication II**) and ordered probit maximum likelihood estimations with *restriction* as an ordered discrete category (Models 3 and 4). Stata version 14 by StataCorp (USA) was used for the estimates.

## 2.5 Methodology for the Invention

Activities of the author of the thesis related to the invention comprised the following: patent search and non-patent literature search and analysis of the search results; consultation on patentability of the invention with the patent examiner Traugott Läänmäe from the Estonian Patent Office; consultations with the patent attorney Margus Sarap; preparation of the documents for filing of the patent application (i.e. specification, claims, etc.) by Margus Sarap; filing of the US Provisional Patent Application (US Provisional Patent Application: US61/771,903, filing date: 03.03.2013). The Inventors/Applicants were Erve Sõõru, Mart Min, Paul Annus, and Raul Land.

The aim of the screening of OSA is to prevent and reduce the risk of serious traffic accidents. Motor vehicle drivers suspected of having moderate or severe OSA during a medical examination should be referred for further examination to determine the presence of moderate to severe obstructive sleep apnea and the need for further treatment. Estonian nation-wide Health Information System (EHIS) is a powerful tool for doctors, granting them easy access to patient electronic health records from single electronic file. By logging into the Patient Portal, patient/driver can review his past doctor visits and current prescriptions, etc. and receive general health advice. eHealth services should aim to save time for both patients and doctors. When applying the EU Directive 2014/85/EU in Estonia, our healthcare system was faced with the problem of finding sleepy drivers with sleep apnea. Drivers accustomed to sleep disorder and sleepiness, as a rule, do not suspect sleep disorder themselves, because with chronic sleepiness a person is unable to assess their sleepiness and therefore cannot complain. The author of the thesis presented possibilities of EHIS for screening obstructive sleep apnea among drivers and integrated the whole process to the EHIS. The whole process is described, when a Health Certificate (HC) applicant logs into the Patient Portal and initiates the process for obtaining the HC and how HC applicant receives driver's license. Screening of obstructive sleep apnea was based on questions with some objective measurements. Early diagnosis of OSA helps to save health and economic costs (Watson, 2016).

Overall background to the invention is the false negative and positive results of sleep studies (incl. pulse oximetry) depending on the person's choice on how to perform sleep investigations. The author of this thesis and Prof Mart Min, Paul Annus and Raul Land from Tallinn University of Technology studied the methods for identifying vital parameters of the patient for evaluating sleep disorders. The methods include determination of the pulse rate and calculation of oxygen saturation while the vital biological data of the patient is being analysed. During these studies, we found that pulse oximetry can be used as a screening or research method, which can also save medical costs. Thus, the present invention was registered as a sleep-breathing diagnostic device for personalised pulse oximetry. This device consists of a wearable pulse oximeter and a unit for the identification of the patient. The device is meant for in-home sleep studies and is able to detect the use by a third person during the study period.

The author and co-authors of the invention found that the data needed to achieve the objectives of the invention may include:

- temperature, thermal scanning of the fingerprint, electrical resistance, pressure, temperature and geometric measurements;
- comparison of the data analysed with data previously stored in the device memory;
- protection of data falsification.

The identification unit comprises the means for extracting the bioimpedance data of the patient. For the impedance electrode solution, we decided that the impedance electrodes arrangement inside the portable pulse oximeter ensures the following: when the pulse oximeter is placed on a finger, one set of impedance electrodes is on one side of the finger and the other set of impedance electrodes is on the other side of the finger. A communication unit and a control unit are for transmitting biological data of the patient to said signal processing unit and for receiving control signals from said control unit to switch on/off bioimpedance electrodes, fingerprint sensors, optical transmitter, temperature sensors, pressure sensors.

Also, the unit can identify the wearer. There are several ways for identification, which consist of all the means mentioned above or a combination of thereof.

To study the patient's vital signs during sleep, the pulse oximeter is placed on the finger and biometric data (bioimpedance data, fingerprint data, or other) is collected and then stored in the device memory, which is protected against forgery. Alternatively, said data is collected previously during the testing and saved into the memory with anti-tamper protection of the oximeter by personalising said oximeter for the patient. The personalised oximeter will be handed out to the patient and according to the study plans, the patient puts oximeter on the finger. The control unit sends the control signal to the sensors to determine whether the oximeter is placed on the correct position on the finger. To protect personal data, the device comprises a module for encrypting the patient's personal and biometric data to ensure its integrity.

# 3 Results

## 3.1 Mismatch of sleep and work arrangements among research and development employees

The results of the regression models on the R&D workers' survey data that the author of the thesis and co-authors of the publications reached are presented in:

1. Appendix 1 of **Publication I** - the OLS, ordered probit and SEM estimates of *sleeplim*
2. Table 2 of **Publication II** - the OLS and ordered probit estimates of *restriction*, along with the Shorrocks-Shapely decomposition (Shorrocks, 1982) of $R^2$ (OLS Model 1) and pseudo-$R^2$ (ordered probit Model 3).

Deriving from the hypotheses for the thesis, all the models incorporate *meq* and *sleephours* as explanatory variables.

The results of the regression models provide support to the hypotheses of the thesis, as outlined in Section 1.7, as follows. In addition, some interesting exploratory findings were identified.

In the study presented in **Publication I**, our research group found that compared to morning- and neither-types, evening-type employees are significantly more likely to perceive that work limits their sleep 'to a large extent' (*sleeplim*=4). Also, evening-types are significantly less likely to feel no work related limitations to sleep (*sleeplim*=1) than the morning- and neither-types. Therefore, the results of the study provide support for **Hypothesis 1**.

The regression modelling results in **Publication II** show that evening types had a significantly higher likelihood to perceive that their sleep regimen limits or has limited their employment opportunities in comparison to morning types. Also, the Mann–Whitney U-test (Mann and Whitney, 1947) shows that at the 95% confidence level, there is a statistically significant difference between evening types and morning types in that perception. Thus, the results of the study provide support for **Hypothesis 2**.

Results of **Publication I** reveal that the longer the sleeping hours of the employee, the more intensely the employee feels work-related limitations on their sleep. That relationship is statistically significant. Therefore, **Hypothesis 3** is supported.

Results of **Publication II** reveal that the longer the sleeping time of the employee, the higher the likelihood that the employee feels constraints to employment options. This statistically significant finding provides support for **Hypothesis 4**.

Results of **Publication I** show that employees who have been granted flexible working hours and a distance work option feel work driven constraints on their sleep regimen with a significantly lower likelihood than the employees who do not have flexibility in the working time and working place. This supports **Hypothesis 5**.

In addition to finding supporting evidence for the hypotheses of the thesis, the results of **Publications I and II** reveal some other drivers of limitations to sleep regimen and employment options among creative knowledge workers. First, creative intensity of work appears to have a negative connection with the work related sleep regimen distraction. Second, employees with worse general health perceive stronger the restrictions that sleep sets on their employment options. Third, gender is another determinant of feeling the constraints that work sets on sleep regimen, with women perceiving those constraints stronger.

## 3.2 Personalisation of sleep studies

A method and a device are provided for personalised pulse oximetry **(Publication III)** of a patient to investigate the sleep disorders, sleep apnea syndrome, wherein wearable pulse oximeter supplied for the patient for home use sleep study is able to identify if the device is used by a third person during the period. Wearable pulse oximetry device is amended with a suitable biometric authentication unit discouraging falsification of the study results. Biometric authentication is achieved by means of physiological biometry **(see Figure 3).**

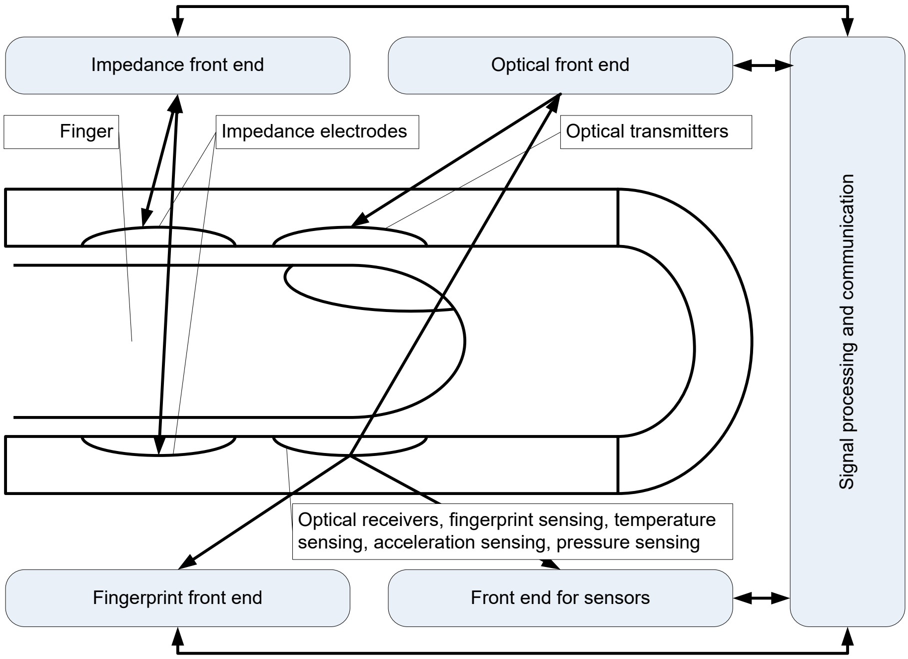



***Figure 3.*** *A schematic overview of the biometric capabilities of pulse oximetry personalisation. Reproduced from* ***Publication III****.*

The author recommends to use the invented device to diagnose obstructive sleep apnea among drivers and other mission critical tasks. The device is expected to be a secure device for identification.

The advantages of a portable pulse oximetry device and method are:

- The possibility of being used by another person excluded;
- A significantly cheaper first-line research method compared to other internationally accepted sleep investigations;
- Wide possibilities for finding sleep disorders;
- Possibility to connect a driver with a medical certificate if a driver's license is applied for in the future;
- Simple and accessible method;
- The results of the study are expected to be of high specificity and sensitivity.

# 4 Discussion

My observation in my family is that my husband prefers to do creative work in the morning hours and does not want to do it in the evening hours, contrary to my preference. The need for our sleep hours is quite similar and we go to bed and wake up more or less at the same time; the same is true for weekends. As a European Sleep Research Society (ESRS) certified somnologist, my belief is that neither of us has sleep disorders according to the International Classification of Sleep Disorders (ICSD-3), and there may be other reasons for the difference in our creative work time. Sleep disorders are mostly underdiagnosed and many less extreme sleep patterns may remain unnoticed, making it difficult to assess sleep related factors without a specific sleep study.

To acquire a better insight into sleep and sleep disorders, different sleep studies have been conducted in both sleep laboratories and out-patient homes (Redline et al., 2007). The number of out-patient sleep surveys has boomed over the last decades as they have become cheaper, simpler and more accurate and informative. Knowledge of various sleep disorders has improved and developed very quickly, and sleep medicine may be considered one of the fastest developing medical fields (Shepard et al., 2005). Earlier, sleep time was considered to be a private rest period for every person, but many connections between sleep and severe health problems have now been found. Many sleep disorders cause significant daytime sleepiness manifested in fatigue, impaired performance, distraction, and coordination disorders. Some sleep disorders develop in an unnoticeable way for humans, or in other words, a person cannot easily suspect a developing sleep disorder. Also, fatigue related to insomnia often cannot be suspected by a person, although fatigue significantly reduces work capacity, the willingness to work and health in general.

While further research is needed to study the link between a human chronotype and employment, the results of our exploratory pilot study outlined in this thesis point to a socially significant issue that evening type person may not have an equal opportunity compared to morning types to find a job because of their inherent daily rhythms, which are difficult to adjust. The study presented in this thesis showed that evening types have a considerably higher probability compared to morning types to feel that their sleep habits restrict their employment options. It is hypothetical, but genetic factors may play a role here. Apart from employment options, it may be thought that evening types also require untraditional time for social activities. However, individuals adapt and feel or are already considering their individual sleep limitations in their work choices. The author of the thesis believes that persons with a circadian rhythm disorder, such as ASPS, or so-called “lark” syndrome, prefer subconsciously working hours early morning times and may choose, e.g., a bakery profession although they may be capable of an intellectually much more demanding job for which the working hours do not match individual preference. The author of the thesis is also convinced that people often have several different sleep disorders or deviations from the social norms about normal sleeping time together, that the circadian rhythm disturbances receive too little attention in medicine as well as by employers, and that it is very difficult to clearly distinguish them from the normal variants. For example, the morning-type people and ASPS and the evening-type people and DSPS have quite similar patterns to sleep and creative hours. The occurrence of circadian rhythm disorders and their overall impact on health and social life is too rarely considered.

The research underlying this thesis also showed that evening-type workers perceive, compared to other chronotypes, their sleep mode to be considerably affected by their work. Traditional work schedules appear better suited for morning- or neither-type preferences, but do not correspond to the natural choice of evening-types. If the sleep-wake cycle due to the set working time does not take into account the human 24-hour clock, it is most likely related to sleep disorders and health in general. As the sleep regime is related to the individual's genetic background, which the worker cannot obviously choose, the evening-type people appear to be unfairly disadvantaged because they have to follow a schedule that does not meet their needs. Understanding these "prima facie" problems and discussing changes in the organisation of working time are necessary. There are, however, social and behavioural factors which may play an important role in the sleep disturbances that individuals may attribute to their work. Working and leisure activities are increasingly intermingled in our daily lives. Using smart devices in the evening before bedtime may be linked to difficulties in falling asleep and insomnia - for example, the use of devices emitting cold light to encourage people to go to bed at bedtime. This can also be associated with younger people having difficulty falling asleep, as younger people are probably the most prone to using smart devices (Van der Maren et al., 2018).

The research presented in this thesis reveals that individuals having longer sleep duration have a higher probability to feel that their sleep habits set constraints to their employment options. Considering the relationship between genetic factors and sleep duration (Utge et al., 2011; Goel, 2017), and its relationship to the chronotype (Ishihara et al., 1988), sleep hours may not be easy to adjust without sacrifices in alertness and overall health. Sleep time is individual and limiting sleep time may negatively affect performance. The author can firmly argue that limiting sleep time to getting up early in the morning can lead to chronic sleep deprivation and a variety of health problems. Failure to synchronise individual sleeping needs with individual circadian rhythms may induce various health related hazards (Veatch et al., 2017).

There are specific questionnaires, scores, and sleep surveys to better understand a person's sleep and to distinguish problematic sleep from normal sleep. People's health and ability to work is affected by the quality of sleep and sleep disorders. A person may not be aware that they have a prolonged sleep disorder, and that it is their inherently long sleep time that restricts job choices. Once again, sleep disorders are usually underdiagnosed. For example, chronic insomnia appears in approximately 12-20% of people (Schutte-Rodin et al., 2008). Also, sleep-related breathing disorder (SRBD) may cause severe hypersomnia or long sleep time. By applying the same working hours to people with different sleeping hours, the exact beginning and end of the working time, we do not take into account their specifics and do not take into account their individual needs. The author of the thesis can assume that the health and social life of these people may suffer as a result. When an individual's sleep is disturbed, he or she is also not efficient and competitive at work. Those who are not ready to sacrifice their sleeping habits and prefer good sleep to good work can have limits to their work options. The results of this study on the sleep duration and work options linkage are generally in agreement with earlier studies by Antillon et al. (2014) and Ásgeirsdóttir and Ólafsson (2015).

The research summarised in the thesis finds that workers having opportunities available for working time and workplace flexibility are much less affected by work-related sleep restrictions. Similar result has been reached by Takahashi et al. (2010)

and Moen et al. (2011), who have discovered that the choice of working time is associated with a reduction in work-family conflict, better sleep and better health.

The research included in the thesis showed that female workers perceive with a higher likelihood their work as a constraint on their sleep regime. It is important to discuss this result in combination with another finding that men are more likely to get jobs that have flexible work schedules. Moreover, the study finds that, although it has generally been found earlier that women sleep more than men, men's average sleeping time is slightly longer than in women in the sample of our R&D staff. Women might be more conscientious and have more homework to do, thus limiting sleep and leisure time.

Regarding other findings from the studies presented in this thesis, general health can have an effect on the perception of sleep related constraints to employment options, as people with weaker general health may feel limited in their job opportunities in general and because they may not be able to fulfil the job needs due to anomalous sleep (Lauderdale et al., 2016). It can be argued that employers should not take into account the employee's state of health when choosing workforce, at least not from the sleep deprivation related aspect. These findings may merit a political debate, as people's employment is important regardless of their state of health.

Studies using the same sample data (Virkebau and Hazak, 2017; Ruubel and Hazak, 2018; Hazak et al., 2016) show that workers living alone are less likely to utilise flexible work opportunities than people with families. This shades some light on why the research underlying this thesis shows that workers who live alone are perceiving less sleep related limitations to their employment possibilities. People with various family responsibilities who have to follow the time use and preferences of other family members have a number of additional restrictions on sleep time compared to those living alone.

Employers may also be at a disadvantage because they do not know which creative workers do creative work best at the traditional working hours and which do not, so they may underestimate the abilities of some employees from observations from their “nine-to-five” performance. Employers’ consideration and provision of flexibility in working hours and the workplace may lead to a positive effect in sleep and productivity improvements, at least in creative R&D workers.

Limitations arising from the sample size and response rate as well as the specific industry and country focus need to be kept in mind when interpreting the results. Please refer to the enclosed papers (Publications I and II) for further discussion of those aspects.

At the start of the studies for this doctoral thesis, there was lack of validated translated questionnaires in Estonian for sleep disorders diagnostics and the exclusion of study-specific sleep studies were the limiting factors. The author of the thesis is currently leader of the working group of the projects “First-line diagnostic guidelines of sleep disorders among adults” (2019), being thus directly involved in some practical implications and implementations of the results of this doctoral thesis.

There is a link between sleepiness caused by obstructive sleep apnea and traffic accidents, and research and treatment of possible sleep disorders is recommended to ensure safe traffic. The aim of the screening of OSA is to prevent and reduce the risk of serious traffic accidents. The author of the thesis presented possibilities of EHIS for screening of obstructive sleep apnea among drivers and integrated the whole process to the Estonian nation-wide Healthcare Information System. The whole process is described, when a Health Certificate (HC) applicant logs into the Patient Portal and initiates the process for obtaining the HC and how an HC applicant receives driver’s license. Screening of obstructive sleep apnea is based on questions with some objective measurements.

Early diagnosis of OSA helps to save health and economic costs (Watson, 2016). However, some drivers consider their sleep a personal matter, and they do not think they have sleep problems. Apparently, they do not know, in their daily habituation to sleep, that they may have sleep problems. Maybe they are afraid to conduct a sleep study, considering that if they get diagnosed with obstructive sleep apnea, they cannot drive anymore. This is revealed by analysing the results of the study. For example, if a study has been conducted in another person, a study of a patient without a pacemaker is believed to have been performed on a person having a pacemaker installed. It has subsequently become clear that the patient gave an out-patient study to another person, such as his mother who had a pacemaker installed. In this case, the health care professional will also make the wrong treatment decision based on false study data. This led to the idea of creating an invention protecting a patient and a health professional because of possible wrong treatment decisions.

Generally, the field of medical devices includes a wide range of products ranging from personal devices to out-patient clinic and hospital equipment. Diagnostic devices have no therapeutic effect and are used to diagnose, prevent, monitor, treat or alleviate diseases. According to the experiences of the author of the thesis, the use of medical devices for therapeutic purposes and their therapeutic effects are poorly inspected in many countries, probably also in Estonia. The author believes that some people are afraid to use medical devices for diagnostic and therapeutic purposes, because they do not believe in their diagnostic or therapeutic effect. The author hypothesises that individuals regard sleep as a very personal subject and allow it to be studied with great care.

The author of the thesis with co-authors of the invention proposed a method for identifying vital parameters of the wearer of a pulse oximeter for evaluating sleep disorders during sleep, comprising the steps of determining the pulse rate and calculation of oxygen saturation with the analysis of vital biological data of the wearer. A method and a solution for a medical device were provided for personalised pulse oximetry of a patient to investigate the sleep apnea syndrome. Pulse oximetry is a promising and widely used monitoring tool also in modern healthcare systems (Chai-Coetzer et al., 2011; Mechanick et al., 2013). It is a fairly straightforward and non-invasive technology allowing the patient with consistent and relatively stress free supervision. The wearable pulse oximeter supplied for the patient for home use sleep study is able to identify if the device is used by another person during the period.

The suggestion of the author of the thesis is that the wearable pulse oximetry device amended with a suitable biometric authentication unit has an important discouraging effect on falsification of sleep study results. For biometric authentication, different physiological possibilities of biometrics in human body and physiology can be used. The author and co-authors of the invention found that the data needed to achieve the objectives of the invention may include temperature, thermal scanning of the fingerprint, pressure, temperature and geometric measurements. In addition, the authors of the technical solution presented in the thesis conclude that the wearable pulse oximetry device is proposed to be used for screening obstructive sleep apnea among vehicle drivers and other executors of mission critical tasks by using pulse oximetry, involving a secure identification of the patient. This solution has a wide application potential and is expected to be used with other recognised sleep studies. Also, it could be a considerably cheaper first line investigation method compared with PSG or any other multi-channel sleep study. Pulse oximetry has a wide potential of use for detecting sleep disorders and their consequences. It can be combined with the vehicle driver's medical certificate when applying for a driver's license for work in the future as a simple and accessible method. The technical solution of our invention may be of interest to future device manufacturers and testers.

Telemedicine has been developing very quickly in recent years. In their research, Anttalainen et al. (2016) have described an oximeter as a device of continuous technological development and even consider it one of the first and important steps in the field of telemedicine to evaluate the effectiveness of telemonitoring of patients. Our invention could be used in personalised outpatient sleep studies, especially in the diagnosis of sleep disordered breathing, and potentially as an element in carrying out telemonitoring in the future. Continued search for cost-effective diagnostic and therapeutic approaches will make portable diagnostic and therapeutic devices very attractive. This method is likely to save the working time of medical personnel and reduce medical costs.

Data protection with reference to Directive 95/46/EC, General Data Protection Regulation, is another issue of significance. Personal data contain information that enables a person to be identified and the collection and processing of personal data can only take place (in Estonia) if there is a legal basis. Security measures must be used when processing personal data. The person whose data is being processed has the right to be informed about it and has the right of access to personal data concerning them, as well as the right to have their data corrected, deleted, processed, etc. Data protection is generally directed to the protection of privacy, but a large part of personal data processing is done by automated decision-making by various technological solutions, with the possibility to use medical devices for the collection of personal data in the future, such as diagnostic devices for future home sleep surveys.

The author of the thesis has been able to participate as the national representative in European projects "Sleepiness at the wheel across Europe: a survey of 19 countries" (2015) and "Variability in recording and scoring of respiratory events during sleep in Europe: a need for uniform standards" (2016), with current position as leader of the working group of the project "First-line diagnostic guideline of sleep disorders among adults" (2019) and Estonian eHealth for screening obstructive sleep apnea among drivers (2019), which are progressive projects for both Estonia and on international level.

It can be concluded that sleep, sleep disorders, daily work ability, working time preferences, work organisation and factors affecting them are a complex but a promising set of phenomena to study. The results of this research may be regarded as a step forward in this wide area.

# 5 Conclusion

The research presented in this thesis is based on two empirical research papers and an invention that contributes to the area of pulse oximetry, a common sensor for out-patients in sleep studies. Both of the research papers focus on the linkages between sleep regimen and organisation of work, and consequent constraints to employment options and sleep habits among creative R&D employees. The key issue of the investigation in the papers is how chronotype and other personal characteristics in sleep regimen interact with various work arrangements, like flexibility of working time and place, creative intensity of work and other. The pilot studies on which the thesis is based use questionnaire study data of over 150 Estonian creative knowledge workers and the starting point for the research is that standard work schedules may not be optimal because they are not in line with preferences and productivity. The invention presented in the thesis relates to another aspect of the relationship between sleep and work organisation, providing a novel method and device for individual identification during pulse oximetry and various other sleep studies.

The main results deriving from the two research papers on the employees in the sample are as follows:

- Evening-type employees have a much higher probability to feel that their sleep regimen is disturbed by their work than other types of chronotype. While the morning-type employees seem to accommodate with the usual 'nine-to-five' schedules better than the evening types of chronotype do, the evening-type people seem much more disadvantaged by having to follow daily time routines that are not how they would prefer to work.
- Moreover, the evening types have a considerably higher probability to feel that their sleep habits restrict their employment options. As outlined in the literature review, recent advances in sleep studies point to some linkages between genetics and chronotype, meaning that chronotype is not easy to alter. The finding (Publication II) that people with different chronotypes may not be equal in employment opportunities is therefore particularly important.
- Individuals whose sleep duration is higher have a higher probability to feel their sleep habits set constraints to their employment options. Considering that sleep duration is related to individual characteristics, as discussed in the literature review section of the thesis, any sleep duration related constraints to work options may present elements of unjustifiably disadvantaged employment opportunities.
- Employees who can flexibly choose both working time and working place perceive much less time-dependent restrictions on their sleeping habits. This result aligns to previous literature, showing that better control over the timing and place of work may enable better sleep and overall better health.
- Female employees are significantly more likely than men to feel limitations that their sleep regimen poses on their work. In parallel, the study reveals that women are less likely to get jobs that provide flexible work schedules. These findings highlight a gender gap, and a new gender-based understanding of work organisation and sleep.
- Employees whose creative intensity of work is higher are less likely to perceive the limitations that their working poses on sleeping patterns compared to employees whose job has a larger element of non-creative tasks. Considering how non-creative

tasks may distract the creative work and bring along additional strain, potential adverse effects on the sleep of the employee may occur.

While presenting novel results and showing interesting avenues for further research, the empirical studies incorporated into this thesis have their limitations due to a small sample size of 153 employees and potentially remaining sample biases despite the measures taken to mitigate these. Future studies on different and larger samples therefore provide interesting opportunities for expanding the research. Overall, the pilot studies included in the thesis hint that individuals with different chronotype and sleep regimen may need different work schedules as employees cannot choose their individual genetic background for a specific chronotype or inherent sleep regimen.

The invention incorporated into this thesis also looks into personal sleep regimen and work, and seeks to provide novel approaches for sleep investigations by an improved method and device for personalised pulse oximetry. The invention provides a better way of identifying whether a wearable pulse oximeter supplied for a patient for home use sleep study may have been used by a third person during the period. The advantages of a personalised pulse oximeter device and method are cost-effectiveness in the first-line study method, as well as comparatively high specificity and sensitivity compared to PSG or other multi-channel sleep studies in the study of SRBD. The added features to pulse oximetry provided by this invention have a wide potential of use for better detecting sleep disorders and their consequences in a particular individual. For example, there are possibilities to combine it with vehicle drivers' medical certification when applying for a driver's license for work in the future as a simple and accessible method.

Overall, most of the hypothesis posed for the research presented in the thesis found support and the invention solves the applied needs in sleep medicine, as outlined in the aims of the thesis.

# List of figures and photos

**Figure 1.** Distribution of chronotypes by age, gender and years of employment. Author's additions to Roenneberg (2012) and Fisher et al. (2017).

**Figure 2.** Schematic representation of normal sleep in different chronotypes, and different types of circadian rhythm disorders with their hypothetical peak creative time. Adapted from Lu et al. (2006).

**Figure 3.** A schematic overview of the biometric capabilities of pulse oximetry personalisation. Reproduced from Publication III.

**Photo 1.** Example of a pulse oximetry performed by different persons during home studies of a 41-year male at North Estonia Medical Centre in January, 2013. Photos by Erve Sõõru.
A comparison of the A) Investigation performed by a person having artificial cardiac pacemaker programmed at the pulse rate of 60 per minute and B) Investigation performed by the same person after scoring of sleep studies, where he was informed of not really having an artificial cardiac pacemaker.

**Photo 2.** The Epworth Sleepiness Scale (ESS), a self-administered questionnaire with the higher score showing a person's average sleep propensity in daily life or their daytime sleepiness. Photos by Erve Sõõru.
A comparison of A) *ESS (in Estonian) filled by a driver in 2012, before the EU Directive on Driving Licenses* and B) *ESS (in Estonian) filled by the driver in 2016, in fear of losing the license as per the EU Directive on Driving Licenses*.

**Photo 3.** Treatment protocols of obstructive sleep apnea with a continuous positive airway pressure device. Photos by Erve Sõõru.
The comparison of A) patient investigation, when the patient did not sleep with the device on (the device was fixed with the mask to the pillow for nine hours and breathing was not detected) and B) investigation results in the same patient after careful discussion with patient, where Pressure, Sleep Therapy Flags, Normal Mask Fit and Results are available.

## References


**Adan, A., Almirall, H.** (1991). Horne & Östberg morningness-eveningness questionnaire: a reduced scale. Pers Individ Differ., 12: 241–253.

**Adan, A.**, Archer, S. N., Hidalgo, M. P., et al. (2012). Circadian typology: a comprehensive review. Chronobiol Int. 29: 1153–1175.

**Åkerstedt, T.** (2003). Shift work and disturbed sleep/wakefulness. Occup Med (Lond); 53: 89–94.

**Alterman, T.**, Luckhaupt, S. E., Dahlhamer, J. M., et al. (2013). Prevalence Rates of Work Organization Characteristics among Workers in the U.S.: Data from the 2010 National Health Interview Survey. Am J Ind Med.; 56: 647–659.

**Amalakanti, S., Pentakota, M. R.** (2016). Pulse Oximetry Overestimates Oxygen Saturation in COPD. Respiratory Care. 61(4): 423–427.

**Antillon, M.**, Lauderdale, D. S., Mullahy, J. (2014). Sleep behaviour and unemployment conditions. Econ Hum Biol. 14: 22–32.

**Anttalainen, U.**, Melkko, S., Hakko, S., Laitinen, T., Saaresranta, T. (2016). Telemonitoring of CPAP therapy may save nursing time. Sleep Breath; 2016 Dec; 20(4): 1209–1215.

**Arble, D. M.,** Bass, J., Laposky, A. D., et al. (2009). Circadian timing of food intake contributes to weight gain. Obesity (Silver Spring) 17(11): 2100–2102.

**Arnardottir, E. S.**, Verbraecken J., Concalves M., et al.; the National Representatives as Study Collaborators. (2016). Variability in recording and scoring of respiratory events during sleep in Europe: a need for uniform standards. J Sleep Res; 25(2): 144–157.

**Ásgeirsdóttir, T. L., Ólafsson, S. P.** (2015). An empirical analysis of the demand for sleep: evidence from the American time use survey. Econ Hum Biol. 19: 265–274.

**Bassetti, C.**, Dogas, Z., Peigneux, P. (2014). European Sleep Research Society. ESRS European Sleep Medicine Textbook. ISBN 9781119038931.

**Biddle, J.**, Hamermesh, D. (1990). Sleep and the allocation of time. J Polit Economy. 98(5): 922–943.

**Bonsignore, M. R.**, Randerath, W., Riha, R. L., et al. (2014). New rules on driver licensing for patients with obstructive sleep apnoea: EU Directive 2014/85/EU. Eur Resp J 47: 39–41.

**Borbely, A. A.** (1982). A two process model of sleep regulation. Hum Neurobiol; 1: 195–204.

**Borbely, A. A.** (2009). Refining sleep homeostasis in the two-process model. Journal of sleep research; 18: 1–2.

**Caldwell, D. F.**, O'Reilly, C. A. (1990). Measuring person–job fit with a profile-comparison process. J Appl Psychol.; 75: 648–657.

**Canadian Sleep Society, Blackman, A.**, McGregor, C., Dales, R., et al. (2010). Canadian Sleep Society/Canadian Thoracic Society position paper on the use of portable monitoring for the diagnosis of obstructive sleep apnea/hypopnea in adults. Can Respir J; 17: 229–232.

**Carrier, J.**, Monk, T. H., Buysse, D. J., Kupfer, D. J. (1997). Sleep and morningness-eveningness in the middle years of life (20-59 y). J Sleep Res. 6: 230–237.

**Chai-Coetzer, C. L.**, Antic, N. A., Rowland, L. S., et al. (2011). A simplified model of screening questionnaire and home monitoring for obstructive sleep apnoea in primary care. Thorax; 66: 213–219.

**Chan, D.** (2000). Understanding adaptation to changes in the work environment: integrating individual difference and learning perspectives. In: Ferris GR, editor. Research in personnel and human resources management. Vol. 18, p. 1–42.

**Chiner, E.**, Signes-Costa, J., Arriero, J. M. et al. (1999). Nocturnal oximetry for the diagnosis of the sleep apnoea hypopnoea syndrome: a method to reduce the number of polysomnographies? Thorax; 54: 968–971.

**Chung, F.**, Liao, P., Elsaid, H., et al. (2012). Oxygen desaturation index from nocturnal oximetry: a sensitive and specific tool to detect sleep-disordered breathing in surgical patients. Anaesthesia and Analgesia. 114(5): 993–1000.

**Collop, N. A.**, Anderson, W. M., Boehlecke, B., et al. (2007). Clinical guidelines for the use of unattended portable monitors in the diagnosis of obstructive sleep apnea in adult patients. J Clin Sleep Med; 3: 737–747.

**Commission Directive 2014/85/EU** of 1 July 2014 amending Directive 2006/126/EC of the European Parliament and of the Council on driving licenses Text with EEA relevance. OJ L 194, 2.7.2014, p. 10–13 (BG, ES, CS, DA, DE, ET, EL, EN, FR, HR, IT, LV, LT, HU, MT, NL, PL, PT, RO, SK, SL, FI, SV).

**Costa, G.** (1996). The impact of shift and night work on health. Appl Ergon.; 27: 9–16.

**Dijk, D. J., Archer S. N.** (2009). Light sleep, and circadian rhythms: together again. PloS Biol, 7: e1000145.

**Directive 95/46/EC** of the European Parliament and of the Council of 24 October 1995 on the protection of individuals with regard to the processing of personal data and on the free movement of such data. Official Journal L 281, 23/11/1995 P. 0031 – 0050.

**Englemann, H. M.**, Kingshott, R. N., Martin, S. E., Douglas, N. J. (2000). Cognitive function in the sleep apnea/hypopnea syndrome (SAHS). Sleep; 23: Suppl. 4: 102–108.

**Epstein, L. J.**, Kristo, D., Strollo, P. J. Jr., et al.; Adult Obstructive Sleep Apnea Task Force of the American Academy of Sleep Medicine. (2009). Clinical quideline for the evaluation, management, and long-term care of obstructive sleep apnea in adults. J Clin Sleep Med, 5(3), 263–176.

**Ewer, A. K.**, Middleton, L. J., Furmston, A. T., et al. (2011). Pulse oximetry screening for congenital heart defects in newborn infants (PulseOx): a test accuracy study. Lancet. 378(9793): 785–794.

**Fisher, D.**, Lombardi, D. A, Marucci – Wellman, H., Roenneberg, T. (2017). Chronotypes in the US – Influence of age and sex. PLoS One. 21; 12: e0178782.

**Fleetham, J.**, Ayas, N., Bradley, D., et al.; Canadian Thoracic Society Sleep Disordered Breathing Committee.et al. (2011). Canadian Thoracic Society 2011 guideline update: diagnosis and treatment of sleep disordered breathing. Can Respir J; 18: 25–47.

**Folkard, S.**, Lombardi, D. A., Tucker, P. T. (2005). Shiftwork: Safety, Sleepiness and Sleep. Ind Health; 43: 20–23.

**Fu, E. S.**, Downs, J. B., Schweiger, J. W., et al. (2004). Supplemental oxygen impairs detection of hypoventilation by pulse oximetry. Chest. 126 (5): 1552–1558.

**Fugate, M.**, Kinicki, A. J., Ashforth, B. E. (2004). Employability: a psycho-social construct, its dimensions, and applications. J Vocat Behav. 65: 14–38.

**Gais, S. and Born, J.** (2004). Declarative memory consolidation: mechanisms acting during human sleep. Learn Mem; 11: 679–685.

**Gan, Y.**, Yang, C., Tong, X., et al. (2015). Shift work and diabetes mellitus: a meta-analysis of observational studies. Occup Environ Med.; 72: 72–78.

**Ghosh, D.**, Macay, T. W., Riha R. L. (2016). European Union directive 2014/85/EU on driver licensing in obstructive sleep apnoea: early experiences with its application in the UK. Breathe, 2016 Sep; 12(3): e59–e63.

**Goel, N.** (2017). Genetic markers of sleep and sleepiness. Sleep Med Clin. 12 (3): 289–299.

**Golden, L.**, Henly, J. R., Lambert, S. (2013). Work schedule flexibility: a contributor to happiness? J Soc Res Pol.; 4: 107–135.

**Golembiewski, R. T., Proehl, C. W.** (1978). A survey of the empirical literature on flexible workhours: character and consequences of a major innovation. Acad Manage Rev.; 3: 837–853.

**Grandner, M. A.**, Patel, N. P., Gehrman, P. R., et al. (2010). Who gets the best sleep? Ethnic and socioeconomic factors related to sleep complaints. Sleep Med. 11 (5): 470–478.

**Greenwood, K. M.** (1995). An evaluation of the Circadian Type Questionnaire. Ergonomics; 38: 347–360.

**Hall, J. C., Rosbach, M., Young, M.** (2018). The discoveries of molecular mechanisms for the circadian rhythm: The 2017 Nobel Prize in Physiology or Medicine. By Huang, R. C. in Biomed J.; 41: 5–8.

**Hastings, M. H.**, Brancaccio, M., Maywood, E. S. (2014). Circadian pacemaking in cells and circuits of the suprachiasmatic nucleus. J Neuroendocrinol; 26: 2–10.

**Hatori, M.**, Vollmers, C., Zarrinpar, A., et al. (2012). Time-restricted feeding without reducing caloric intake prevents metabolic disease in mice fed a high-fat diet. Cell Metab 15(6): 848–860.

**Hazak, A.**, Männasoo, K., Virkebau, M. (2017). Effects of work arrangements on creative R&D work outcomes. Eastern European Economics, 55(6): 500–521.

**Hazak, A.**, Ruubel, R., Virkebau, M. (2019). When would creative R&D employees like to work? International Journal of Organizational Analysis, 27(3): 596–612.

**Hazak, A.**, Tint, P., Virkebau, M, et al. (2016). Social innovation potential in working arrangements of R&D employees: repeated employee survey from Estonia. In: Proceedings of IEEE International Conference on Emerging Technologies and Innovative Business Practices for the Transformation of Societies (EmergiTech); 2016 Aug 3-6; Balaclava, Mauritius, New York (NY): IEEE. P. 210–213.

**Hedner, J.**, White, D. P., Malhotra, A., et al. (2011). Sleep staging based on autonomic signals: a multicenter validation study. J Clin Sleep Med; 7: 301–306.

**Herbert, L. J.**, **Wilson I. H.** (2012). Pulse oximetry in low-resource settings. Breathe; 9: 90–98.

**Hillman, D. R., Lack, L. C.** (2013). Public health implications of sleep loss: the community burden. Med J Aust; 199: S7–10.

**Hofstra, W. A., de Weerd, A. W.** (2008). How to assess circadian rhythm in humans: a review of literature. Epilepsy Behav; 13: 438–444.

**Horne, J. A.** (1998). Sleep loss and "divergent" thinking ability. Sleep; 11: 528–536.

**Horne, J. A., Ostberg, O. A.** (1976). A self- assessment questionnaire to determine morningness-eveningness in human circadian rhythms. Int. J Chronobiol, 4: 97–110.

**ICSD-3. (2014).** The International classification of sleep disorders, 3nd ed.: Diagnostic and coding manual. Westchester, Illinois: American Academy of Sleep Medicine, 2014.

**Ishihara, K.**, Miyake, S., Miyasita, A., Miyata, Y. (1988). Comparisons of sleep-wake habits of morning and evening types in Japanese worker sample. J Hum Ergol. 17: 111–118.

**Juda, M.**, Vetter, C., Roenneberg, T. (2013). Chronotype modulates sleep duration, sleep quality, and social jet lag in shift-workers. J Biol Rhythms. ; 28: 141–151.

**Kalmbach, D. A.**, Schneider, L. D., Cheung, J., et al. (2017). Genetic basis of chronotype in humans: insights from three landmark GWAS. Sleep; 40.

**Kantermann, T.**, Juda, M., Vetter, C. et al. (2010). Shift-work research: where do we stand, where should we go? Sleep Biol Rhythms; 8: 95–105.

**Karhula, K.**, Härmä, M., Sallinen, M, et al. (2013). Association of job strain with working hours, shift-dependent perceived workload, sleepiness and recovery. Ergonomics; 56: 1640–1651.

**Kelleher, J. F.** (1989). Pulse oximetry. J Clin Monit.; 5: 37–62.

**Kerkhof, G. A.** (1985). Inter-individual differences in the human circadian system: a review. Biol Psychol. 20: 83–112.

**Kryger, M. H.**, Avidan, A. Y., Berry, R. B. (2014). Atlas of Clinical Sleep Medicine, Second edition. Philadelphia, PA, 19103 – 2899.

**Lack, L.**, Bailey, M., Lovato, N., Wright, H. (2009). "Chronotype differences in circadian rhythms of temperature, melatonin, and sleepiness as measured in a modified constant routine protocol". Nature and science of sleep. 1: 1–8. PMID 23616692.

**Levi, F.**, Okyar, A., Dulong, S., et al. (2010). Circadian timing of cancer treatments. Annual Rev Pharmacol Toxicol 50: 377–421.

**Lu, B. S.**, Zee, P. C. (2006). Circadian rhythm disorders. Chest 130: 1915–1923.

**Malhotra, R. K.**, Kirsch, D. B., Kristo, D. A., et al.; American Academy of Sleep Medicine Board of Directors. (2018). Polysomnography for Obstructive Sleep Apnea Should Include Arousal-Based Scoring: An American Academy of Sleep Medicine Position Statement. J Clin Sleep Med. 15; 14(7): 1245–1247.

**Martino, T. A.**, Oudit, G. Y., Herzenberg, A. M., et al. (2008). Circadian rhythm disorganization produces profound cardiovascular and renal disease in hamsters. Am J Physiol Regul Integr Comp Physiol 294(5): R1675–1683.

**Masa Jiménez, J. F.**, Barbé Illa, F., Capote Gil, F., et al.; Working Group. (2007). Resources and delays in the diagnosis of sleep apnea-hypopnea syndrome. Arch Bronchopneumol, 43 (4): 188–198.

**Mechanick, J. I.**, Youdim, A., Jones, D. B., et al. (2013). Clinical practice guidelines for the perioperative, nutritional, metabolic, and nonsurgical support of the bariatric surgery patient – 2013 update: cosponsored by American Association of Clinical Endocrinologists, the Obesity Society, and American Society for Metabolic & Beriatric Surgery. Endocr Pract; 19: 337–372.

**Megdal, S. P.**, Kroenke, C. H., Laden, F., et al. (2005). Night work and breast cancer risk: A systematic review and meta-analysis. Eur J Cancer.; 41: 2023–2032.

**Mellner, C.**, Kecklund, G., Kompier, M. (2016). Boundaryless work, psychological detachment and sleep: does working 'anytime–anywhere' equal employees are 'always on'? In: De Leede J, editor. New ways of working practices: antecedents and outcomes. Bingley: Emerald; p. 29–47.

**Merikanto, I.**, Kronholm, E., Peltonen, M., et al. (2015). Circadian preference links to depression in general adult population. J Affect Disord; 188: 143–148.

**Merikanto, I.**, Lahti, T., Kronholm, E., et al. (2013). Evening types are prone to depression. Chronobiol Int. 5: 719–725.

**Miller, B. H.**, Olson, S. L., Turek, F. W., et al. (2004). Circadian clock mutation disrupts estrous cyclicity and maintenance of pregnancy. Curr Biol 14(15): 1367–1373.

**Moen, P.**, Kelly, E. L., Tranby, E., Huang, Q. (2011). Changing work, changing health: can real work-time flexibility promote health behaviors and well-being? J Health Soc Behav.; 52: 404–429.

**Monk, T. H.**, **Buysse, D. J.** (2014). Chronotype, bed timing and total sleep time in sensors. Chronobiol. Int., 31: 655–659.

**Morgenthaler, T. I.**, Lee-Chiong, T., Alessi, C. et al.; Standards of Practice Committee of the American Academy of Sleep Medicine. (2007). Practice parameters for the clinical evaluation and treatment of the circadian rhythm disorders. An American Academy of Sleep Medicine report. Sleep; 30: 1445–1459.

**Nakamura, T. J.**, Ebihara, S., Shinohara, K. (2011). Reduced light response of neuronal firing activity in the suprachiasmatic nucleus and optic nerve of cryptochrome-deficient mice. PLoS One; 6: e28726.

**Norfleet, E. A.**, **Watson, C. B.** (1985). Continuous mixed venous oxygen saturation measurement: a significant advance in hemodynamic monitoring? J Clin Monit.; 1(4): 245–258.

**Ohayon, M. M**., Smolensky, M.H., Roth T. (2010). Consequences of shiftworking on sleep duration, sleepiness, and sleep attacks. Chronobiol Int.; 27: 575–589.

**Paine, S. J.**, Gander, P. H., Travier, N. (2006). The epidemiology of morningness/ eveningness: influence of age, gender, ethnicity, and socioeconomic factors in adults (30-49 years). J Biol Rhythms. 21: 68–76.

**Patel, N. P.**, Grandner, M. A., Xie, D., et al. (2010). “Sleep disparity” in the population: poor sleep quality is strongly associated with poverty and ethnicity. BMC Public Health. 10(1): 475.

**Penneys, R.** (1952). Oxygen tension of tissues by the polarographic method. IV. Skin oxygen tension vs. arterial oxygen saturation; relationship to oxyhaemoglobin dissociation curve. J Clin Invest.; 31(2): 204–208.

**Penzel, T.**, et al. (2010). Ambulatory diagnosis of OSA and new technologies. Eur Respir Monogr; 50: 136–149.

**Pittman, S. D.**, Ayas, N. T., MacDonald, M. M., et al. (2004). Using a wrist-worn device on peripheral arterial tonometry to diagnose obstructive sleep apnea: in-laboratory and ambulatory validation. Sleep; 27: 923–933.

**Pulakos, E. D.**, Arad, S., Donovan, M. A., et al. (2000). Adaptability in the workplace: development of a taxonomy of adaptive performance. J Appl Psychol. 85: 612–624.

**Punjabi, N. M.** (2008). The epidemiology of adult obstructive sleep apnoea. Proc. Am. Thorac. Soc., 5: 136–143.

**Randler, C.** (2008). Morningness-eveningness and satisfaction with life. Soc Indic Res. 86: 297–302.

**Randler, C.** (2013). German version of the reduced Morningness–Eveningness Questionnaire (rMEQ). Biol. Rhythm Res., 44 (2013), pp. 730–736.

**Redline, S.**, Budhiraja, R., Kapur, V., et al. (2007).The scoring of respiratory events: reliability and validity. J Clin Sleep Med; 3: 169–200.

**Roenneberg, T.** (2012). Internal time: chronotypes, social yet lag, and why you’re so tired. Cambridge (MA): Harvard University Press.

**Roenneberg, T.**, Kuehnle, T., Juda, M., Kantermann, T., et al. (2007). Epidemiology of the human circadian clock. Sleep Med. Rev. 11: 429–438.

**Roenneberg, T.**, Kuehnle, T., Pramstaller, P. P., et al. (2004). A marker for the end of adolescence. Curr Biol.; 14: R1038–R1039.

**Ruubel, R.**, **Hazak, A.** (2018). Disparities in Knowledge Employees' Actual, Contractual, and Desired Working Schedules. Knowledge Management: An International Journal, 18(1), 17–30.

**Sack, R. L.**, Auckley, D., Auger, R. R., Carskadon, M. A., et al.; American Academy of Sleep Medicine. (2007). Circadian rhythm sleep disorders: part I, basic principles, shiftwork and jet lag disorders. An American Academy of Sleep Medicine review; 30: 1460–1483.

**Sack, R. L.**, Auckley, D., Auger, R. R., et al.; American Academy of Sleep Medicine (2007). Circadian rhythm sleep disorders: part II, advanced sleep phase disorder, delayed sleep phase, free-running disorder, and irregular sleep-wake rhythm. An American Academy of Sleep Medicine review. Sleep; 30: 1484–1501.

**Sack, R. L.**, Lewy, A. J., Blood, M. L., et al. (1992). Circadian rhythm abnormalities in totally blind people: incidence and clinical significance. J Clin Endocrinol Metab; 75: 127–134.

**Saper, C. B.**, Scammell, T. E., Lu, J. (2005). Hypothalamic regulation of sleep and circadian rhythms. Nature; 437: 1257–1263.

**Saulle, R.**, Bernardi, M., Chiarini. M., et al. (2018). Shift work, overweight and obesity in health professionals: a systematic review and meta-analysis. Clin Ter. Jul-Aug; 169(4): e189-e197.

**Schlosshan, D.**, **Elliott, M. W.** (2004). Sleep. 3: Clinical presentation and diagnosis of the obstructive sleep apnoea hypopnoea syndrome. Thorax. 59 (4): 347–352.

**Schutte-Rodin, S.**, Broch, L., Buysse, D., et al. (2008). Clinical guideline for the evaluation and management of chronic insomnia in adults. J Clin Sleep Med; 4: 487–504.

**Sedigh, G. I.**, Devlin, R. A., Grenier, G. (2017). Revisiting the relationship between wages and sleep duration: the role of insomnia. Econ Hum Biol. 24: 125–139.

**Severinghaus, J. W.**, **Honda, Y.** (1987). History of blood gas analysis. VII. Pulse oximetry. J Clin Monit.; 3 (2): 135–138.

**Shepard, J. W. Jr. 1.**, Buysse, D. J., Chesson, A. L. Jr., et al. (2005). History of the development of sleep medicine in the United States. J Clin Sleep Med. 2005 Jan 15; 1(1): 61–82.

**Skene, D. J.**, **Arendt, J.** (2007). Circadian rhythm sleep disorders in the blind and their treatmment with melatonin. Sleep Med; 8: 651–655.

**Steiger, A.**, Holsboer, F. (1997). Neuropeptides and human sleep. Sleep. Nov; 20 (11): 1038–1052.

**Summa, K. C.**, Vitaterna, M. H., Turek, F. W. (2012). Environmental perturbation of the circadian clock disrupts pregnancy in the mouse. PloS One 7(5): e37668.

**Taillard, J.**, Philip, P., Bioulac, B. (1999). Morningness/eveningness and the need for sleep. J Sleep Res. 8: 291–295.

**Takahashi, M.**, Iwasaki, K., Sasaki, T., et al. (2011). Worktime control dependent reductions in fatigue, sleep problems, and depression. Appl Ergon.; 42: 244–250.

**Tang, Y.**, Preuss, F., Turek, F. W., et al. (2009). Sleep deprivation worsens inflammation and delays recovery in mouse model of colitis. Sleep Med 10(6): 597–603.

**Triarhou, L. C.** (2006). The percipient observations of Constantin von Economo on encephalitis lethargica and sleep disruption and their lasting impact on contemporary sleep research. Brain Research Bulletin; 69: 244–258.

**Utge, S.**, Kronholm, E., Partonen, T., et al. (2011). Shared genetic background for regulation of mood and sleep: association of GRIA3 with sleep duration in healthy Finnish women. Sleep. 34: 1309–1316.

**Van der Maren, S.,** Moderie, C., Duclos, C., et al. (2018). Daily Profiles of Light Exposure and Evening Use of Light-emitting Devices in Young Adults Complaining of a Delayed Sleep Schedule. J Biol Rhythms. 2018 Apr; 33(2): 192–202. doi: 10.1177/0748730418757007. Epub 2018 Feb 20.

**Van Cauter, E.**, Spiegel, K., Tasali, E., Leproult, R. (2008). Metabolic consequences of sleep and sleep loss. Sleep medicine; 9 Suppl 1: S23–28.

**Van Dongen, H. P**., Maislin, G., Mullington, J. M., Dinges, D. F. (2003). The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep; 26: 117–126.

**Veatch, O. J.**, Keenan, B. T, Gehrman, P. R. (2017). Pleiotropic genetic effects influencing sleep and neurological disorders. Lancet Neurol.; 16: 158–170.

**Verbraecken, J.** (2012). Obstructive sleep apnea syndrome. In: ERS handbook: Respiratory Sleep Medicine (Eds) by Simonds, A. K., de Backer, W. 25.

**Vetter, C.**, Devore, E. E., Ramin, C. A., et al. (2015). Mismatch of Sleep and Work Timing and Risk of Type 2 Diabetes. Diabetes Care; 38: 1707–1713.

**Vetter, C.**, Devore, E. E., Wegrzyn, L. R., et al. (2016). Association between Rotating Night Shift Work and Risk of Coronary Heart Disease among Women. JAMA; 315: 1726–1734.

**Vetter, C.**, Fischer, D., Matera, J. L., Roenneberg, T. (2015). Aligning work and circadian time in shift workers improves sleep and reduces circadian disruption. Curr Biol CB; 25: 907–911.

**Viola, A. U.**, Archer, S. N., James, L. M., et al. (2007). PER3 polymorphism predicts sleep structure and waking performance. Curr Biol; 17: 613–618.

**Virkebau, M.**, **Hazak, A.** (2017). What type of the research and development employees use flextime? International Journal of Organizational Diversity, 17(2), 1-9.

**Watson, N. F.** (2016). Health Care Savings: The Economic Value of Diagnostic and Therapeutic Care for Obstructive Sleep Apnea. J Clin Sleep Med. 2016 Aug 15; 12(8): 1075–1077.

**Williamson, A.**, Lombardi, D. A., Folkard, S., et al. (2011). The link between fatigue and safety. Accident Analysis & Prevention; 43: 498–515.

**Wulff, K.**, Porcheret, K., Cussans, et al. (2009). Sleep and circadian rhythm disturbances: multiple genes and multiple phenotypes. Curr Opin Genet Dev; 19: 237–246.

**Zamarron, C.**, Gude, F., Barcala, J. et al. (2003). Utility of oxygen saturation and heart rate spectral analysis obtained from pulse oximetric recordings on the diagnosis of sleep apnea syndrome. Chest; 123: 1567–1576.

**Zavada, A.**, Gordijn, M. C., Beersma, et al. (2005). "Comparison of the Munich Chronotype Questionnaire with the Horne-Östberg's Morningness-Eveningness Score". Chronobiol. Int. 22 (2): 267–278.

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# Abstract

# Mismatch of Sleep and Work Arrangements among Research and Development Employees and Personalisation of Sleep Studies

Interest in sleep and sleep disorders has grown during the recent decades. Sleep problems are increasingly common; they interfere with people's daily coping and can impair work performance. Individuals can be categorised by their circadian rhythms as morning-type, evening-type or neither-type. Traditionally, all of those are expected to follow "nine-to-five" work schedules where individual needs cannot be necessarily accommodated. However, working in the early morning hours may not be appropriate for all chronotypes and some types would prefer working hours that are different from the traditional ones. The research presented in this thesis focused on creative R&D employees who might be expected to need a flexible work schedule and whose creative work result is more dependent on alertness and good sleep. The linkages between circadian rhythms on socio-economic behaviour have been scarcely studied, but this area of research could be of practical value for policy, management and individual needs.

Frequent sleep disorder – obstructive sleep apnea – among drivers is a key contributor to road accidents due to daytime sleepiness. The number of sleep tests has increased after the implementation of the European Union (EU) Driving License Directive in 2015, which required suspects to be screened for sleep apnea. According to the author's observation in her everyday work, some people gave the device that is meant for home use sleep study to a third person to register their results. One of the reasons is that by registering sleep study results of a third person, it would misinform medical personnel and lead to that person being able to keep their driver's license. The role of person identification sensors and methods for patient identification in sleep studies have not yet been covered in previous studies.

The aim of this thesis was to find out which chronotypes are disturbed by their work patterns and which types of chronotypes suffer from their sleeping habits in employment options. The purpose of those pilot studies is to initiate the research in those topics while larger scale research should be undertaken in future. The research presented in this thesis employs questionnaire study data of Estonian research and development professionals (n = 153). Linkages between employment options, chronotypes, sleep duration and different individual and work characteristics were studied. The research uses different statistical methods for finding the results.

The second goal was to invent a solution for a device for person identification during sleep studies. Pulse oximetry is the most widely used sensor for investigations of sleep-disordered breathing and early identification of hypoxaemia and level of oxyhemoglobin desaturation during the night.

The results of the questionnaire based study presented in the thesis showed that employment options appeared to be more limited among evening types and workers who have longer sleeping hours. Evening type workers, women and those whose work is with a lower creative intensity are more likely to feel that their work is setting restrictions on their sleep. Also, those workers who have no flexible work hours and no teleworking possibilities feel more the impact of work on their sleep patterns. The studies presented in the thesis suggest that giving working time and workplace flexibility and avoiding excessive administrative burdens on creative workers improves

their sleep. This contributes to their well-being and performance. Employees are expected to find it difficult to change their sleep related preferences because chronotypes may have a genetic background. It may be suggested that people with different sleep needs may not have equal opportunities to find work in creative jobs.

Our research group developed a method and a device for personalised pulse oximetry in patient's sleep investigation. Wearable pulse oximeter complemented with the invention and supplied for the patient for home use sleep study is able to identify if the device is used by a third person during the period. Although both pulse oximetry and biometric detection principles are already well known, different physical methods and devices for personalising oximetric data have not been previously combined. Portable devices are simple and relatively cheap. Further studies should focus on the diagnostic opportunities and cost effects associated with the widespread use of information technology in outpatient research. In addition, this solution may be considered in personalised telemonitoring.

# Lühikokkuvõte
# Teadus- ja arendustöötajate une ja töökorralduse ebakõlad ning uneuuringute personaliseerimine

Huvi une ja unehäirete vastu on viimastel aastakümnetel kasvanud. Unehäireid esineb järjest sagedamini, need häirivad inimeste igapäevast toimetulekut ja võivad halvendada töötulemusi. Inimesi võib liigitada oma ööpäevaste rütmide järgi hommikutüübiks, õhtutüübiks ja liigitamata tüübiks. Tavapäraselt eeldatakse, et kõik eelnimetatud tüübid peavad järgima „üheksast viieni“ töögraafikuid, kus individuaalseid vajadusi ei ole võimalik arvestada. Siiski võib arvata, et kõikidele kronotüüpidele ei sobi töötamine varastel hommikutundidel ja mõned tüübid eelistaksid tööaega, mis on erinev tavapärasest. Oma töös keskendusin loovatele teadus- ja arendustöötajatele, kes võiksid eeldatavalt vajada paidlikku töögraafikut, ja kelle loomingulise töö tulemuslikkus sõltub enam vaimsest erksusest ja heast unest. Tsirkadiaanrütmi seoseid sotsiaal-majandusliku käitumisega on vähe uuritud, kuid tegemist on uue uurimisvaldkonnaga, mis on praktilise väärtusega poliitika kujunduses, juhtimises ja individuaalsete vajadustega arvestamisel.

Sagedane unehäire – obstruktiivne uneapnoe on liiklusõnnetuste puhul oluline riskitegur, mis on tingitud päevasest liigunisusest. Uneuuringute arv kasvas pärast Euroopa Liidu (EL) juhilubade direktiivi rakendamist 2015. aastal, mis määras, et uneapnoe kahtlusega isikuid peab uneapnoe esinemise suhtes uurima. Autor märkas oma igapäevatöös, et mõned inimesed andsid koduseks kasutamiseks mõeldud uneuuringu seadme kolmandale isikule tulemuste registreerimiseks. Üheks põhjuseks on meditsiinipersonali eksitamine kolmanda isiku tulemuste kaudu ning seeläbi oma juhtimisõiguse säilitamine. Uneuuringutel kasutatavate identifitseerimisandurite ja identifitseeritavate uneuuringumeetodite rolli ei ole varasemates uuringutes veel käsitletud.

Käesoleva doktoritöö eesmärk oli välja selgitada, millist tüüpi kronotüüpide unereziim on häiritud töökorralduse tõttu, ning leida, milliste kronotüüpide loominguline tööhõive kannatab magamisharjumuste tõttu. Selle pilootuuringu eesmärk on teema algatamine, jättes samas ruumi edasisteks suuremahulisemateks uuringuteks.

Uuring põhineb küsitlusel, kuhu on kaasatud Eesti loomingulised teadus- ja arendustegevuse töötajad (N = 153). Uuriti kronotüüpe, une kestust ning erinevaid individuaalseid ja tööomadusi. Uurimistöös on kasutatud erinevaid statistilisi meetodeid tulemuste leidmiseks.

Töö teiseks eesmärgiks oli leiutada uneuuringuteks kasutatav isiku tuvastamise meetod ja seade. Kõige sagedamini kasutatav andur unehäirete uurimiseks on pulssoksümeeter, millel on oluline roll hüpokseemia varajases avastamises ja oksühemoglobiini desaturatsiooni demonstreerimisel öötundidel.

Doktoritöös esitatud küsitluspõhise uuringu tulemused näitasid, et oma töövõimalusi tunnetasid unest enam piiratud olevat õhtust tüüpi ja pikema uneajaga töötajad. Õhtutüüpi töötajad, naised ja madalama loomingulise intensiivsusega töö tegijad tunnetasid, et töö seab piiranguid nende unele. Töötajad, kellel on võimalus valida paindlikku töögraafikut ja töötegemise kohta, tunnetasid tööst tingitud piiravat mõju unerežiimile vähem. Doktoritöös esitatud uurimustest selgus, et tööaja ja töökoha paindlikkuse võimaldamine ning ülemääraste administratiivkohustuste vältimine parandab loovate teadus- ja arendustöötajate und, aidates sellega kaasa töötajate heaolu ja töötulemuste parandamisele. Arvatavalt on töötajatel oma une-eelistusi raske muuta, sest kronotüüpidel võib olla geneetiline taust. Võib arvata, et erineva

unevajadusega inimestel ei pruugi olla võrdsed võimalused töö leidmiseks, vähemasti teadus- ja arendustegevuses.

Doktoritöö autori ja kolleegide arendusena valminud meetod ja seade on mõeldud individuaalse uneuuringu läbiviimiseks kodustes tingimustes. Personaliseeritud pulssoksümeeter suudab tuvastada, kas seadet kasutab uuringu perioodi jooksul keegi kolmas isik.

Ehkki nii pulssoksümeetria seadmed kui ka biomeetrilised tuvastuspõhimõtted on teada juba pikemat aega, ei ole varem oksümeetriliste andmete personaliseerimiseks erinevaid füüsikalisi meetodeid ja seadmeid kokku viidud. Kaasaskantavad seadmed on lihtsad ja suhteliselt odavad. Loodetavasti keskendutakse edaspidi ambulatoorsetes uuringutes kasutatava infotehnoloogia laialdase kasutamisega seotud diagnostikavaldkonnale ja kuludele. Lisaks võib selle lahenduse kasutamist kaaluda personaliseeritud telemonitooringus.

# Appendix 1

**Publication I**

Hazak, Aaro; Sõõru, Erve; Hein, Heili; Männasoo, Kadri (2018). Effects of work arrangements on the sleep regimen of creative R&D employees. International Journal of Occupational Safety and Ergonomics. Taylor & Francis. Epub ahead of print. DOI: 10.1080/10803548.2018.1504854 (Web of Science, Scopus)

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# Effects of work arrangements on the sleep regimen of creative research and development employees

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Traditional ‘nine-to-five’ working schedules do not consider individual characteristics. We identify what types of employees suffer from the adverse effects of work arrangements on their sleep regimen based on a survey of Estonian creative research and development (R&D) employees ($N = 153$). We present ordinary least squares and ordered probit regression estimates and recursive structural equation model estimates of the employees’ perceived level of sleep regimen disruption. We find that evening-type employees, women and employees with a lower creative intensity of work perceive with a significantly higher probability that work limits their sleep, while employees having flexibility in both working time and workplace feel less impacted by work-driven constraints on their sleep regimen. Granting working time and workplace flexibility and avoiding the allocation of excessive administrative duties to creative R&D employees may have a considerable positive impact on improving their sleep, thus contributing to improving their well-being and work results.

**Keywords:** sleep; morningness–eveningness; flexible work; gender; research and development jobs; Estonia

## 1. Introduction

The timing and location of work as well as other aspects of work arrangements may have a strong impact on the sleep regimen and overall quality of life for employees. While there is ample evidence that shift and night work arrangements compromise sleep and various health outcomes [1–5], it is important to note that traditional ‘nine-to-five’ work schedules do not accommodate the heterogeneous individual characteristics of ‘normal’ daytime employees either. The person–job fit literature, such as the study by Caldwell and O’Reilly [6], highlights the importance of the fit between individual characteristics and the work environment in improving work performance. Flexible working time is a key work environment factor, allowing employees to adjust their working time according to their personal preferences, and work at the time when they feel most productive. In a review of earlier studies on working time arrangements, Golembiewski and Proehl [7] point to the positive effect that flexible working time can have on gaining control of work and personal life. Golden et al. [8] show that flexible working time arrangements are associated with increased happiness.

A major advantage of flexible working time is that it enables employees to be in tune with their circadian rhythms – the biological phenomena relating to the sleep–wake timing preferences of individuals, also known as morningness–eveningness. Based on their circadian rhythm, people can be broadly classified into three chronotypes: morning, neither or evening type. Roughly 40% of the population displays distinct morningness or eveningness patterns, while the rest is neither type [9,10]. Morning-type individuals wish to go to sleep and wake up early, and are more alert in the early part of the day. In contrast, evening-type individuals prefer to go to sleep and wake up late, and are more alert in the evening. Although a chronotype appears to have a genetic background [11], it can be influenced by individual (e.g., age, gender) and environmental (e.g., place of residence, exposure to light) factors as well [9]. The phase lags in circadian rhythmic functions can be large, ranging from 2 to 12 h between morning types and evening types [9].

Ill-fitting work schedules that clash with the circadian clock can have adverse effects on the employee. If the sleep–wake cycle is out of sync with the individual circadian rhythms, the risk of several health issues increases [12]. Juda et al. [13] investigate how a chronotype affects tolerance to shift work in terms of social jet lag (i.e., sleep deficit accumulation during workdays and sleeping longer during days off), sleep duration and sleep disturbance. They establish that during night shifts, morning-type employees had reduced sleep duration, high social jet lag and increased levels of sleep disturbance. Similar symptoms were noted for evening-type employees during early shifts.

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Increased control over working time, however, can have a positive effect on workers' sleep and health outcomes. Takahashi et al. [14] explore the connection between working time control and fatigue, sleep problems and depression symptoms in a large sample of both daytime and shift workers. The authors discover that greater working time control, measured as both control over working hours and days off, was linked with decreases in incomplete recovery, insomnia symptoms (for men only), daytime sleepiness and depression symptoms. Moen et al. [15] conducted a longitudinal survey in a natural experiment set-up to see whether participation in a corporate initiative giving employees greater working time flexibility predicted changes in their health-related behaviours. They found that partaking in the initiative predicted positive changes in several respects, including sleeping almost an hour longer at night, exercising more, not going to the workplace when sick and visiting the doctor when ill. Mellner et al. [16] find in a large sample of professional employees that the ability of psychological detachment from work may be a key mechanism in mediating the effects of flexibility in working time and workplace on sleep. Männasoo and Meriküll [17] found that research and development (R&D) engagement in new member states of Central and Eastern Europe is highly volatile, which might affect the work arrangements and related stress factors and occupational health issues of R&D employees in this region.

In this study, we seek to identify which types of employees feel that work limits their sleep regimen. Furthermore, we examine whether the arrangement of work (e.g., working time flexibility, distance work option, creative intensity of work) has an effect on the perceived extent to which the sleep regimen is limited by work. For these purposes, we exploit data collected via our original repeated survey among creative R&D employees in Estonia. We present ordinary least squares (OLS) regressions, ordered probit regressions as well as recursive structural equation estimates of how much employees perceived their sleep regimen to be disrupted by work.

## 2. Materials and methods

### *2.1. Participants*

This study uses data collected through our original online repeated survey among Estonian creative R&D employees. The sample was compiled based on 2012 (i.e., latest available) statistical data on R&D by Statistics Estonia. We omitted 'technicians' and 'supporting staff' from the population and focused solely on 'researchers' due to the more creative nature of their work. In equivalent employees working full-time, there were roughly 4400 creative R&D employees in Estonia in the period 2010–2014. Considering the restrictions that teaching schedules at education institutions and work schedules at medical institutions set on time and workplace flexibility and work arrangements in general, we excluded approximately 2400 creative R&D employees in education and healthcare from the population of our study. In addition, as working arrangements in micro-entities and larger organizations differ, around 1000 employees (full-time equivalent) who work at research institutes and micro-enterprises with fewer than 15 creative R&D employees were excluded from the population.

Therefore, the total population of creative R&D employees of interest for our study is approximately 1000, representing 23 different employers. While we invited all 23 employers from the private and public sector to participate in our study, 11 employers accepted the invitation. Eight employers joined during the first wave of the study carried out in spring–summer 2015 and three employers joined in the identical second wave in winter 2016. We pooled the data from the two waves for this article. Similar to Hazak et al. [18,19], Virkebau and Hazak [20], Ruubel and Hazak [21] and other papers using the same dataset, regarding recurring participants, we selected randomly which responses to consider. Additionally, contradictory and irrelevant responses were removed. The final sample comprised 153 employees – around 15% of the total population of 1000 (see Table 1). Creative R&D employees from public research institutes made up 21% of the final sample, while 28% worked at private companies in banking, 23% in technology, 15% in R&D and 14% in the information technology industry.

As the employees had the opportunity to join the sample only if their employer participated in the study, the individuals were not selected from the population randomly but through a company-based selection. Also, survey completion versus non-completion may be related to a selection bias. These selection biases are addressed by weighting the responses by respondent gender and their employer's field of activity, with the purpose of aligning the sample to the gender and activity field characteristics of the population. In all regression models, we have clustered standard errors either by employer or employer–gender, etc., interaction terms in order to account for any unobserved company-level patterns in the responses.

### *2.2. Instruments*

The questionnaire included a total of 90 questions addressing various aspects of the organization of work, work results, sleepiness, sleep patterns, tiredness, health as well as socio-demographic information. A 5-point Likert-type scale is used to gain a response to the question 'To what extent do you feel that your work is limiting or has limited your sleep regimen?' (*sleeplim*) and this is used as the dependent variable in the models presented in this article. Explanatory variables have been selected based on our research hypotheses and extant literature.

One of these is the score on the reduced morningness–eveningness questionnaire (rMEQ) by Adan and Almirall [22]. Ordered categories of employee-reported sleeping hours have been incorporated as a further explanatory variable. Other independent variables reflect different aspects of work arrangements and job satisfaction. Age, gender, number of family members and education are the main control variables for individual socio-demographic characteristics in the models. The health factor represents the respondent's general health condition based on a set of survey questions. Refer to Table 1 for a detailed overview of the model variables and description of the subjects, and to Figure 1 for histograms of some key model variables.

Table 1. Model variables and description of the subjects.

| Variable | Description | All ($N = 153$) | Males ($n = 87$) | Females ($n = 66$) |
|---|---|---|---|---|
| Dependent | | | | |
| *sleeplim* | To what extent do you feel that your work is limiting or has limited your sleep regimen? | | | |
| | 1 = *not at all* (base) | 29 | 37 | 20 |
| | 2 = *to a small extent* | 40 | 38 | 42 |
| | 3 = *somewhat* | 16 | 15 | 18 |
| | 4 = *to a large extent* | 12 | 9 | 15 |
| | 5 = *totally* | 3 | 1 | 5 |
| Explanatory | | | | |
| *flextime* | Flexible (= 1) *vs* fixed (= 0) working time arrangement of the employee | 75 | 82 | 67 |
| *place* | It is possible (= 1) *vs* not possible (= 0) to work from a location suitable for the employee (e.g., home) as often as he/she likes | 27 | 28 | 27 |
| *workhours* | Employee reported average working hours/working day | 10.10 (1.67) | 10.10 (1.44) | 10.11 (1.95) |
| *atwork* | Employee reported share of working hours at the workplace out of total working hours/working day | 0.82 (0.13) | 0.81 (0.14) | 0.84 (0.11) |
| *creatime* | Employee reported share of creative work in total working time of the employee (%) | 52.71 (21.41) | 52.05 (21.05) | 53.59 (22.01) |
| *context* | 1 = *work as part of an R&D team* (base) | 78 | 76 | 80 |
| | 2 = *work as part of a team, which comprises mostly non-R&D employees* | 16 | 18 | 14 |
| | 3 = *individual employee in the R&D area* | 6 | 6 | 6 |
| *nature* | 1 = *permanent work* (base) | 90 | 92 | 87 |
| | 2 = *non-permanent work, with a duration of >1 year* | 7 | 5 | 11 |
| | 3 = *non-permanent work, with a duration of <1 year* | 3 | 3 | 2 |
| *job satisfaction* | To what extent are you satisfied with your work? (5-point Likert-type scale, 1 = *not at all* to 5 = *totally*) | 3.76 (0.73) | 3.76 (0.75) | 3.76 (0.72) |
| *meq* | Reduced morningness–eveningness questionnaire score, 1–25 scale ranging from *Definitely an evening-type* to *Definitely a morning-type* | 14.73 (3.53) | 14.98 (3.57) | 14.39 (3.49) |
| *sleephours* | Employee reported average sleeping hours/day on the scale: | | | |
| | 1 = *< 6 h* (base) | 7 | 6 | 8 |
| | 2 = *6–7 h* | 50 | 49 | 50 |
| | 3 = *7–8 h* | 38 | 39 | 36 |
| | 4 = *8–9 h* | 6 | 6 | 6 |
| | 5 = *> 9 h* | 0 | 0 | 0 |
| *gender* | Male (= 1) *vs* female (= 0) | 57 | 100 | 100 |
| *age* | Age in years | 38.76 (11.51) | 37.72 (12.19) | 40.12 (10.48) |
| *family* | Employee-reported number of people living together with the employee | 1.66 (1.46) | 1.72 (1.54) | 1.58 (1.36) |

(*Continued*).

Table 1. Continued.

| Variable | Description | All ($N$ = 153) | Males ($n$ = 87) | Females ($n$ = 66) |
|---|---|---|---|---|
| *education* | Educational level: | | | |
| | 1 = *primary education* (base) | 0 | 0 | 0 |
| | 2 = *secondary education* | 8 | 14 | 0 |
| | 3 = *vocational education* | 3 | 5 | 0 |
| | 4 = *undergraduate degree* | 30 | 33 | 26 |
| | 5 = *master's degree* | 41 | 33 | 51 |
| | 6 = *PhD* | 18 | 15 | 23 |
| *educationy* | Years of education starting from primary education | 16.58 (2.66) | 15.96 (2.85) | 17.39 (2.14) |
| *fhealth* | General health condition factor (with overall Kaiser–Meyer–Olkin measure of sampling adequacy of the factor 0.6), comprising: | 0.00 (0.81) | 0.05 (0.81) | −0.07 (0.81) |
| | (1) 'Do you have high blood pressure or have you ever used medicine for high blood pressure?' (yes = 1) | 20 | 22 | 18 |
| | (2) 'Do you suffer or have you suffered from diseases that significantly affect your mental fatigue?' (5-point Likert-type scale, 1 = *never* to 5 = *often*) | 1.71 (0.95) | 1.75 (0.97) | 1.67 (0.93) |
| | (3) 'Does your disease or injury interrupt you while doing your daily job?' (5-point Likert-type scale, 1 = *no obstacles* to 5 = *not able to work*) | 1.58 (0.73) | 1.57 (0.77) | 1.58 (0.68) |
| | (4) 'How many workdays have you been absent from work due to disease or medical examination in the past 12 months?'(5-point scale, 1 = *none* to 5 = *100–365 days*) | 1.75 (0.72) | 1.77 (0.69) | 1.71 (0.76) |
| | (5) Body mass index (continuous) | 24.65 (3.90) | 25.35 (3.11) | 23.72 (4.61) |

Note: Data presented as mean (*SD*) for continuous and ordered variables; percentage of respondents shown for binary and categorical variables. R&D = research and development.

### *2.3. Statistical analysis*

We present six alternative estimates of the employees' perceived extent to which their sleep regimen was limited by work. The six different model set-ups enable us to consider various angles of how work arrangements affect sleep, and to test the robustness of the results. The first two regression models (see Models 1 and 2 in Table A1 in Appendix 1) represent the OLS continuous estimations of the dependent variable. Models 3 and 4 show the ordered probit maximum likelihood estimations of the ordered discrete categories of the dependent variable. As the distribution of the dependent variable is skewed and non-normal, as expected, the ordered probit estimations led to a better descriptive power for the dependent variable compared to the OLS model. The ordered probit model therefore functions as the main model for reporting the study results in the following sections. We compiled the fifth and sixth models, however, as structural equation models (SEMs) in order to take into account the selection due to it being certain types of employees that opt for flexible working time (represented by the *flextime* variable) as well as for creativity intensive positions (represented by the *creatime* variable). The fully observed recursive SEMs (Models 5 and 6) present the perceived extent to which work limited the employees' sleep (*sleeplim*) as the final stage-dependent variable, whereas the ordered probit estimates of *sleeplim* in the main equation contain *flextime* and *creatime* as the endogenous selection variables among other explanatory variables. The three-dimensional SEM includes in parallel a probit estimation of *flextime* and an OLS estimation of *creatime*. Compared to the OLS and ordered probit estimates of the dependent variable, the SEMs thereby help to control for the selection mechanisms for positions with a flexible working time option and for creativity intensive positions. The SEMs (Models 5 and 6) differ from each other only in terms of incorporating the flexible working time variable (*flextime*) as a separate explanatory variable (Model 6), as opposed to in interaction with the flexibility in the workplace (*place*) variable (Model 5). For the estimations we use the cmp (conditional mixed process) module of Stata version 14.

## 3. Results

The results of the six alternative models are presented in Table A1 in Appendix 1. The models show overall qualitatively similar results for model fit and coefficient estimates.

From all six models we find the morningness–eveningness type of employee to have a statistically significant connection with his/her perception of sleep regimen limitations due to work. We find that relationship to be

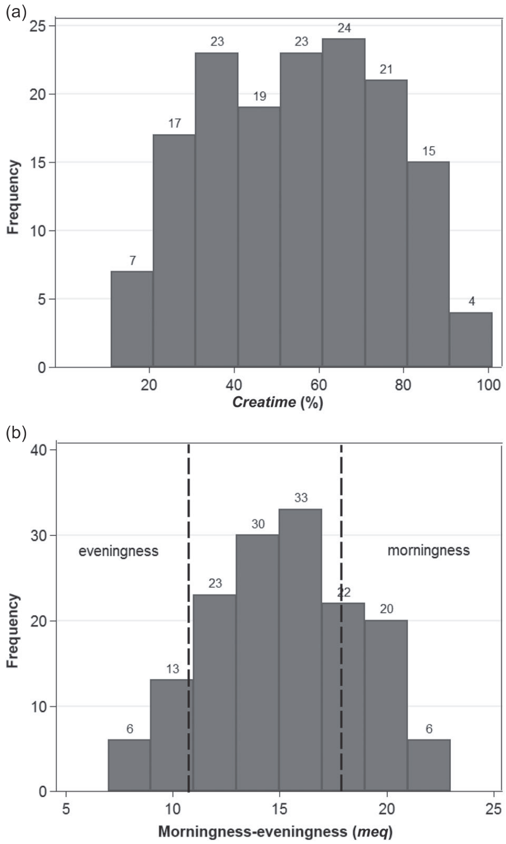


Figure 1. Histograms of (a) creative intensity of work (*creatime*) and (b) morningness–eveningness (*meq*).

non-linear, as illustrated in Figures 2a and 2b. Compared to morning-type employees and the neither type, evening-type employees feel with a significantly higher probability that work limits their sleep *to a large extent* (*sleeplim* = 4; Figure 2b). The opposite applies to perceiving no work-related limitations to sleep (*sleeplim* = 1; Figure 2a) – evening-type employees perceive it with a significantly lower probability in comparison to neither-type and morning-type people.

From the results of Models 1–4 we find that employees who have flexibility in both working time and workplace (i.e., *flextime* = 1 and *place* = 1) perceive the limitations that their work sets on their sleep regimen at a significantly lower probability than the employees who do not enjoy both of these liberties. For a graphical illustration of that complex relationship, refer to Figures 2c and 2d, where probabilities of an employee perceiving that his/her work is limiting or has limited his/her sleep regimen *not at all* (*sleeplim* = 1; Figure 2c) and *to a large extent* (*sleeplim* = 4; Figure 2d) are shown for the different combinations of flexible working time and distance work (i.e., flexible working place) options and different morningness–eveningness (*meq*) levels (adjusted ordered probit estimates at means based on Model 3). We note, however, that support for this finding is limited as the marginal effects of *flextime* and *place* individually do not appear statistically significant in Models 1–4, and Models 5 and 6, where a selection mechanism into positions with flexible working time has been taken into account, do not reveal any post-selection effect of flexible working time or distance work option on the perceived extent of limitations that work sets on sleep.

We find from all six alternative model estimates that creative intensity has a statistically significant negative relationship with the employee's perception of working time distracting his/her sleep regimen. Refer to Figures 2e and 2f for an illustration of the significant decrease in the probability of an employee feeling his/her work being a large (Figure 2f) or no (Figure 2e) limiter of sleep along with the increase in the creative intensity of work.

As an expected result, we find a statistically significant negative relationship between sleeping hours and the level of perceived work-related limitations on sleep. The linkages between employee-reported sleeping hours and perceived limitations of sleep regimen caused by work are illustrated in Figures 2g and 2h.

In the ordered probit-based estimates of *sleeplim* from Models 3–6 we find gender to be a statistically near-significant determinant of the level of perceived limitations of sleep regimen caused by work. Compared to women, men have a 12–13 percentage point higher probability of feeling that work does not set any limits on their sleep rhythms. Women have a 6 percentage point higher probability of perceiving that work has limited their sleep regimen *to a large extent*. Refer to Table A2 in Appendix 1 for the marginal effects. Women are, however, less likely than men to get access to jobs providing flexible working time, as becomes evident from Models 5 and 6.

In order to test whether the perceived limitations of sleep regimen caused by work might be driven by overall satisfaction with work by the employee, we have included job satisfaction as an additional explanatory variable in Models 2 and 4. As can be seen from Table A1 in Appendix 1, both of these models reveal that perceived work-related limitations on sleep are not related to the job satisfaction of the employee. This, along with controlling for the effect of sleeping hours in all models, provides some additional support for the finding that work arrangements, chronotype and gender are related to perceived limitations that work sets on the sleep regimen of an employee.

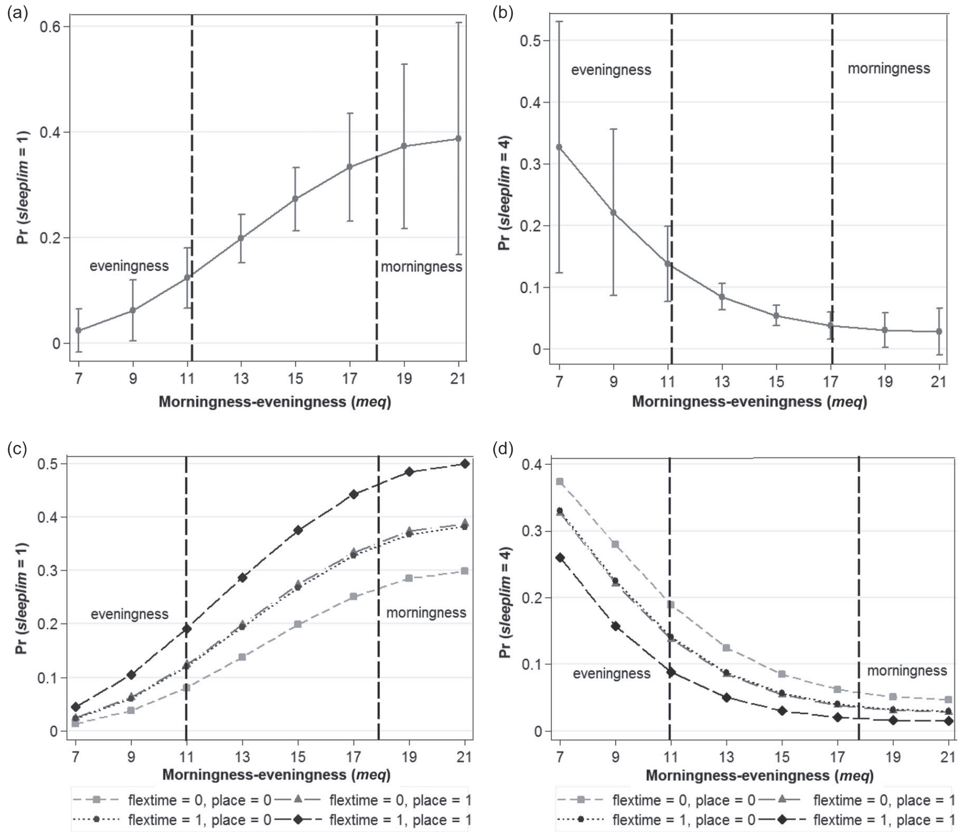


Figure 2. Probabilities of an employee perceiving that his/her work is limiting or has limited his/her sleep regimen *not at all* (left panel; a, c, e, g) and *to a large extent* (right panel; b, d, f, h) for (a–d) different morningness–eveningness (*meq*), (e, f) creative intensity (*creatime*) and (g, h) sleeping time (*sleephours*) levels.
Note: Adjusted ordered probit estimates at means with error bars denoting 90% confidence intervals based on Model 2.

## 4. Discussion and conclusions

The purpose of this study was to identify which type of creative R&D employees suffer from the adverse effects of work arrangements on their sleep regimen. The starting point for the investigation was the notion that traditional daily (‘nine-to-five’) work schedules might not account for individual characteristics, including their circadian rhythm. Several significant findings arise from our study. First, evening-type employees feel that their sleep regimen is significantly more disturbed by work compared to the other chronotypes. This result reveals that traditional work schedules, where the working day usually starts between 08:00 or 09:00, accommodate the preferences of morning or neither types but do not comply with the natural choices of evening types. A sleep–wake cycle that is out of sync with the individual’s inner circadian clock is associated with adverse outcomes concerning sleep and health in general [12,13]. Moreover, considering that the sleep regimen is connected to the individual’s genetic background, which evidently cannot be chosen or changed by the employee, evening-type people appear to be unfairly disadvantaged by having to follow a daily schedule not in compliance with their needs. An understanding of these severe problems and discussions on changing working time arrangements are necessary at both employer and regulator levels, as well as in society at large.

Second, we find that female employees have a considerably higher probability of perceiving their work as strongly limiting their sleep regimen, while being less likely than men to gain access to jobs with flexible work schedules. We note that although it has been generally found that women sleep more than men [23], in our sample of Estonian R&D employees the sleeping hours of men are slightly longer. It could be possible that women feel more distracted by paid work because they do more unpaid work at home, thus limiting the overall time available for sleep and leisure. In Estonia, women do a disproportionately high share of care-giving and household tasks, even in

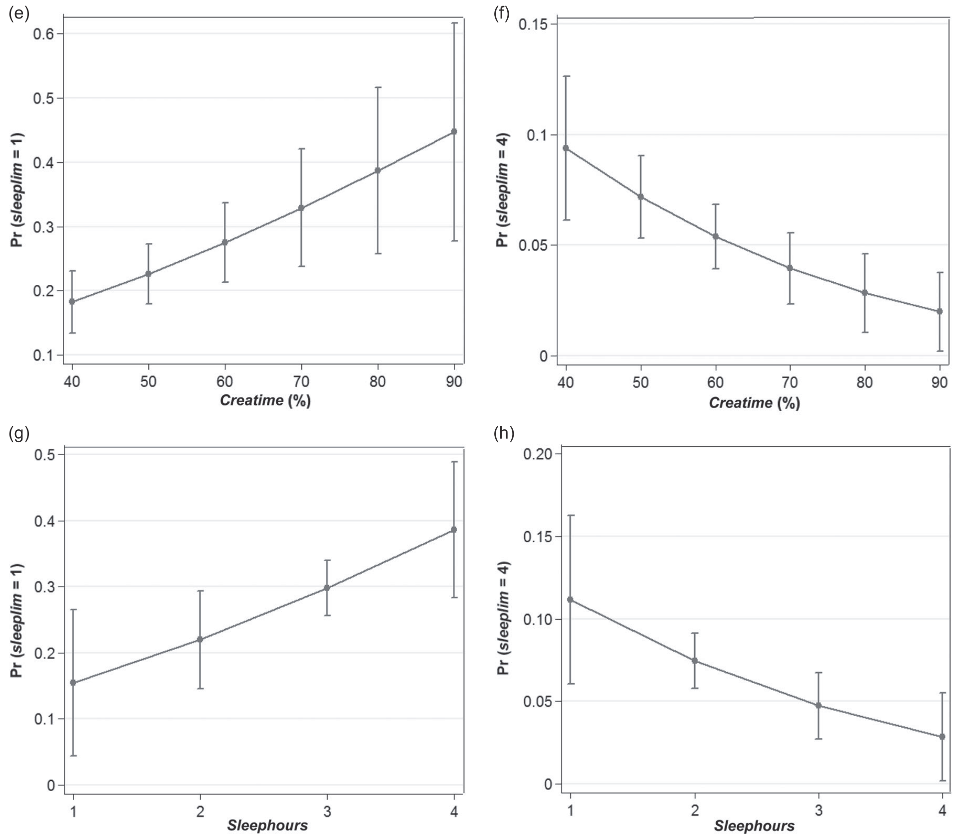


Figure 2. Continued.

families where both spouses work full-time [24], and this might explain our study results in addition to the lower likelihood of women getting jobs with flexitime.

Third, our results show some support for the finding that employees who have flexibility in both working time and working place feel significantly less impacted by work-driven constraints on their sleep regimen. This result corroborates the findings by Takahashi et al. [14] and Moen et al. [15], who uncover that added control over working time is associated with reduced work–life conflict, better sleep and improved health. More generally, our findings support the discoveries by Golden et al. [8], who show that greater working time flexibility is linked with increased happiness, and Anderson et al. [25], who discovered that employees experience more positive feelings (e.g., happiness, enthusiasm, alertness) and less negative feelings (e.g., fear, anxiety, guilt) on days when they telework as opposed to when they work in the office.

Finally, we find employees with a higher creative intensity of work less affected by the limitations that work sets on their sleep, in comparison to employees with a higher share of administrative and other non-creative tasks. A possible explanation for this is that creative assignments are the preferred and primary work tasks of a creative R&D employee, and remain the basis on which the employee is evaluated, while administrative and other non-creative tasks are (non-preferred) side-tasks. These tasks must be done, but they are largely ‘invisible’ and are not highly valued by the employees themselves or by their supervisors. As administrative tasks can distract and slow down the creative work, and can be related to additional strain, less time may be available for the principal creative tasks of the employee and possibly also for sleep.

The presented findings make novel contributions. However, this study has limitations. While the results are statistically significant, they are based on a small sample of 153 employees. Also, individuals in the population were approached on a company basis, and thus could only participate if their employer agreed to the study. Besides, survey completion by the respondent might have incurred a selection bias. To an extent, these selection biases were addressed by weighting of the sample to align it with population characteristics regarding the respondent's gender and the employer's industry. Furthermore, clustering standard errors by employer was used to account for dependencies in such clusters. Nevertheless, all selection biases cannot be offset. Considering future studies, similar analyses on larger samples in different countries and/or different professions could be a motivating research path.

Despite these limitations, our study points to the mismatch between the traditional 'nine-to-five' work schedules of creative R&D employees and the individual characteristics of the employees, such as their inner circadian clock. Evening-type and female R&D employees are significantly more likely to be limited by the adverse effects of work on their sleep regimen. Not only is the well-being of employees impaired when they feel that work limits their sleep, but the employers are also disadvantaged, as they are potentially underutilizing the creative capabilities of their employees. Granting working time and working place flexibility may have a major positive impact on improving the sleep of creative R&D workers as well as improving productivity. Avoiding the allocation of excessive administrative duties to creative R&D employees may have a further positive effect on their sleep.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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## References

[1] Costa G. The impact of shift and night work on health. Appl Ergon. 1996;27:9–16. doi:10.1016/0003-6870(95)00047-X

[2] Åkerstedt T. Shift work and disturbed sleep/wakefulness. Occup Med (Lond). 2003;53:89–94. doi:10.1093/occmed/kqg046

[3] Kantermann T, Juda M, Vetter C, et al. Shift-work research: where do we stand, where should we go? Sleep Biol Rhythms. 2010;8:95–105. doi:10.1111/j.1479-8425.2010.00432.x

[4] Ohayon MM, Smolensky MH, Roth T. Consequences of shiftworking on sleep duration, sleepiness, and sleep attacks. Chronobiol Int. 2010;27:575–589. doi:10.3109/07420521003749956

[5] Karhula K, Härmä M, Sallinen M, et al. Association of job strain with working hours, shift-dependent perceived workload, sleepiness and recovery. Ergonomics. 2013;56:1640–1651. doi:10.1080/00140139.2013.837514

[6] Caldwell DF, O'Reilly CA. Measuring person–job fit with a profile-comparison process. J Appl Psychol. 1990;75:648–657. doi:10.1037/0021-9010.75.6.648

[7] Golembiewski RT, Proehl CW. A survey of the empirical literature on flexible workhours: character and consequences of a major innovation. Acad Manage Rev. 1978;3:837–853. doi:10.5465/amr.1978.4289294

[8] Golden L, Henly JR, Lambert S. Work schedule flexibility: a contributor to happiness? J Soc Res Pol. 2013;4:107–135.

[9] Adan A, Archer SN, Hidalgo MP, et al. Circadian typology: a comprehensive review. Chronobiol Int. 2012;29:1153–1175. doi:10.3109/07420528.2012.719971

[10] Roenneberg T. Internal time: chronotypes, social yet lag, and why you're so tired. Cambridge (MA): Harvard University Press; 2012.

[11] Kalmbach DA, Schneider LD, Cheung J, et al. Genetic basis of chronotype in humans: insights from three landmark GWAS. Sleep. 2017;40.

[12] Veatch OJ, Keenan BT, Gehrman PR, et al. Pleiotropic genetic effects influencing sleep and neurological disorders. Lancet Neurol. 2017;16:158–170. doi:10.1016/S1474-4422(16)30339-8

[13] Juda M, Vetter C, Roenneberg T. Chronotype modulates sleep duration, sleep quality, and social jet lag in shift-workers. J Biol Rhythm. 2013;28:141–151. doi:10.1177/0748730412475042

[14] Takahashi M, Iwasaki K, Sasaki T, et al. Worktime control-dependent reductions in fatigue, sleep problems, and depression. Appl Ergon. 2011;42:244–250. doi:10.1016/j.apergo.2010.06.006

[15] Moen P, Kelly EL, Tranby E, et al. Changing work, changing health: can real work-time flexibility promote health behaviors and well-being? J Health Soc Behav. 2011;52:404–429. doi:10.1177/0022146511418979

[16] Mellner C, Kecklund G, Kompier M, et al. Boundaryless work, psychological detachment and sleep: does working 'anytime–anywhere' equal employees are 'always on'? In: De Leede J, editor. New ways of working practices: antecedents and outcomes. Bingley: Emerald; 2016. p. 29–47.

[17] Männasoo, K, Meriküll J. R&D, credit constraints, and demand fluctuations: comparative micro evidence from ten new EU members. East Eur Econ. 2014;52(2):49–64. doi:10.2753/EEE0012-8775520203

[18] Hazak A, Männasoo K, Virkebau M. Effects of work arrangements on creative R&D work outcomes. East Eur Econ. 2017;55:500–521. doi:10.1080/00128775.2017.1381567

[19] Hazak A, Tint P, Virkebau M, et al. Social innovation potential in working arrangements of R&D employees: repeated employee survey from Estonia. In: Proceedings of IEEE International Conference on Emerging Technologies and Innovative Business Practices for the Transformation of Societies (EmergiTech); 2016 Aug 3–6; Balaclava, Mauritius. New York (NY): IEEE. p. 210–213. doi:10.1109/EmergiTech.2016.7737340

[20] Virkebau M, Hazak A. What type of research and development employees use flextime? Int J Organ Divers. 2017;17:1–9. doi:10.18848/2328-6261/CGP/v17i02/1-9

[21] Ruubel R, Hazak A. Disparities in knowledge employees' actual, contractual and desired working schedules. Knowl Manag. 2018;1:17–30.

[22] Adan A, Almirall H. Horne & Östberg morningness–eveningness questionnaire: a reduced scale. Pers Individ Differ. 1991; 12:241–253. doi:10.1016/0191-8869(91)90110-W

[23] Burgard SA, Ailshire JA. Gender and time for sleep among U.S. adults. Am Sociol Rev. 2013; 78:51–69. doi:10.1177/0003122412472048

[24] Mehe kodu on maailm, naise maailm on kodu? [Man's home is the world, woman's world is her home?] Tallinn: Statistics Estonia; 2011. Estonian.

[25] Anderson AJ, Kaplan SA, Vega RP. The impact of telework on emotional experience: when, and for whom, does telework improve daily affective well-being? Eur J Work Organ Psychol. 2015; 24:882–897. doi:10.1080/1359432X.2014.966086

## Appendix 1

Table A1. Ordinary least squares (OLS), ordered probit and structural equation model (SEM) estimates of *sleeplim*.

| Variable | Model 1: OLS | Model 2: OLS | Model 3: ordered probit | Model 4: ordered probit | Model 5: SEM | Model 6: SEM |
|---|---|---|---|---|---|---|
| Main equation, estimation | | | | | *oprobit* | *oprobit* |
| *flextime* = 0 # *place* = 1[a] | −0.165 | −0.091 | −0.244 | −0.160 | −0.242 | – |
| | (0.59) | (0.60) | (0.83) | (0.83) | (0.82) | – |
| *flextime* = 1 # *place* = 0 | −0.165 | −0.164 | −0.227 | −0.225 | 0.104 | – |
| | (0.19) | (0.19) | (0.21) | (0.21) | (0.87) | – |
| *flextime* = 1 # *place* = 1 | −0.381*** | −0.346*** | −0.528*** | −0.483*** | −0.196 | – |
| | (0.12) | (0.10) | (0.17) | (0.16) | (0.77) | – |
| *flextime* (yes = 1) | – | – | – | – | – | 0.013 |
| | – | – | – | – | – | (0.80) |
| *workhours* | −0.004 | 0.007 | −0.007 | 0.008 | −0.006 | −0.012 |
| | (0.05) | (0.05) | (0.06) | (0.06) | (0.06) | (0.06) |
| *atwork* | 0.761 | 0.752 | 0.737 | 0.732 | 0.715 | 1.001 |
| | (0.54) | (0.55) | (0.71) | (0.72) | (0.70) | (0.74) |
| *creatime* | −0.010** | −0.010** | −0.015** | −0.015*** | −0.022*** | −0.021*** |
| | (0.00) | (0.00) | (0.01) | (0.01) | (0.00) | (0.01) |
| *context* = 2 | −0.100 | −0.937 | −0.125 | −0.113 | −0.018 | −0.041 |
| | (0.32) | (0.30) | (0.37) | (0.36) | (0.25) | (0.27) |
| *context* = 3 | 0.175 | 0.213 | 0.074 | 0.126 | 0.150 | 0.166 |
| | (0.30) | (0.29) | (0.35) | (0.31) | (0.46) | (0.45) |
| *nature* = 2 | 0.193 | 0.194 | 0.323§ | 0.318§ | 0.313§ | 0.354* |
| | (0.16) | (0.16) | (0.22) | (0.22) | (0.21) | (0.19) |
| *nature* = 3[a] | −0.374* | −0.413* | −0.413 | −0.496 | −0.403 | −0.399 |
| | (0.19) | (0.21) | (0.31) | (0.38) | (0.31) | (0.32) |
| *job satisfaction* | – | −0.089 | – | −0.114 | – | – |
| | – | (0.10) | – | (0.14) | – | – |
| *meq* | −0.378** | −0.399** | −0.361** | −0.383** | −0.357** | −0.342** |
| | (0.14) | (0.13) | (0.15) | (0.15) | (0.15) | (0.16) |
| $meq^2$ | 0.010** | 0.011** | 0.009* | 0.009* | 0.008* | 0.008* |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| *sleephours* | −0.229* | −0.225* | −0.242* | −0.236* | −0.239* | −0.215§ |
| | (0.11) | (0.11) | (0.14) | (0.14) | (0.14) | (0.13) |
| *gender* (male = 1) | −0.377 | −0.367 | −0.492* | −0.481* | −0.531§ | −0.518§ |
| | (0.24) | (0.25) | (0.28) | (0.28) | (0.32) | (0.32) |
| *age* | −0.001 | −0.002 | 0.000 | −0.001 | 0.002 | 0.004 |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| *family* | −0.046 | −0.045 | −0.085§ | −0.087* | −0.084§ | −0.081§ |
| | (0.04) | (0.04) | (0.05) | (0.05) | (0.05) | (0.05) |
| *education* = 3 | −1.023* | −0.995* | −1.598* | −1.536* | −1.541* | −1.487* |
| | (0.52) | (0.54) | (0.84) | (0.87) | (0.81) | (0.78) |
| *education* = 4 | −0.515§ | −0.522§ | −0.597* | −0.608* | −0.554* | −0.553* |
| | (0.30) | (0.30) | (0.32) | (0.32) | (0.33) | (0.30) |
| *education* = 5 | −0.571 | −0.534 | −0.652 | −0.607 | −0.586 | −0.621 |
| | (0.44) | (0.47) | (0.52) | (0.55) | (0.56) | (0.52) |
| *education* = 6 | −0.696§ | −0.665 | −0.883§ | −0.844§ | −0.773 | −0.863* |
| | (0.48) | (0.49) | (0.54) | (0.55) | (0.61) | (0.48) |
| Scores for factor *fhealth* | 0.105 | 0.094 | 0.130 | 0.117 | 0.129 | 0.118 |
| | (0.10) | (0.30) | (0.12) | (0.13) | (0.12) | (0.11) |
| Constant | 7.062*** | 7.380*** | – | – | – | – |
| | (1.21) | (1.27) | – | – | – | – |

(*Continued*).

Table A1. Continued.

| Variable | Model 1: OLS | Model 2: OLS | Model 3: ordered probit | Model 4: ordered probit | Model 5: SEM | Model 6: SEM |
|---|---|---|---|---|---|---|
| *creatime*, estimation | – | – | – | – | *OLS* | *OLS* |
| | – | – | – | – | – | – |
| *age* | – | – | – | – | 0.087 | 0.087 |
| | – | – | – | – | (0.25) | (0.25) |
| *gender* (male = 1) | – | – | – | – | 1.704 | 1.703 |
| | – | – | – | – | (3.77) | (3.77) |
| *education* | – | – | – | – | 2.379*** | 2.379*** |
| | – | – | – | – | (0.64) | (0.64) |
| *constant* | – | – | – | – | 11.437* | 11.436* |
| | – | – | – | – | (6.52) | (6.52) |
| *flextime*, estimation | – | – | – | – | *probit* | *probit* |
| | – | – | – | – | – | – |
| *age* | – | – | – | – | −0.017 | −0.017 |
| | – | – | – | – | (0.01) | (0.01) |
| *gender* (male = 1) | – | – | – | – | 0.532*** | 0.532*** |
| | – | – | – | – | (0.20) | (0.20) |
| *education* | – | – | – | – | 0.073** | 0.072** |
| | – | – | – | – | (0.04) | (0.04) |
| *meq* | – | – | – | – | 0.011 | 0.010 |
| | – | – | – | – | (0.03) | (0.03) |
| *context* = 2 | – | – | – | – | −0.837* | −0.840* |
| | – | – | – | – | (0.44) | (0.44) |
| *context* = 3 | – | – | – | – | −0.659 | −0.660 |
| | – | – | – | – | (0.58) | (0.57) |
| Constant | – | – | – | – | −0.241 | −0.221 |
| | – | – | – | – | (0.61) | (0.60) |
| cut_1_1, constant | – | – | −6.341*** | −6.705 | −6.281*** | −5.796*** |
| | – | – | (1.26) | (1.38) | (1.55) | (1.46) |
| cut_1_2, constant | – | – | −4.985*** | −5.360 | −4.944*** | −4.463*** |
| | – | – | (1.27) | (1.40) | (1.50) | (1.41) |
| cut_1_3, constant | – | – | −4.169*** | −4.536 | −4.141*** | −3.662*** |
| | – | – | (1.25) | (1.36) | (1.45) | (1.35) |
| cut_1_4, constant | – | – | −3.069*** | −3.428 | −3.060** | −2.584** |
| | – | – | (1.12) | (1.22) | (1.30) | (1.20) |
| lnsig_2, constant | – | – | – | – | 2.972*** | 2.972*** |
| | – | – | – | – | (0.04) | (0.04) |
| atanhrho_12, constant | – | – | – | – | 0.108§ | 0.098§ |
| | – | – | – | – | (0.07) | (0.06) |
| atanhrho_13, constant | – | – | – | – | −0.160 | −0.136 |
| | – | – | – | – | (0.47) | (0.45) |
| atanhrho_23, constant | – | – | – | – | 0.257* | 0.255* |
| | – | – | – | – | (0.15) | (0.15) |
| $R^2$ | 0.393*** | 0.395*** | – | – | – | – |
| Pseudo-log-likelihood | – | – | −172.15*** | −171.47*** | −919.96*** | −920.75*** |
| Number of observations | 150 | 150 | 150 | 150 | 153 | 153 |

[a]Only four observations in this category, no contextual significance.
§$p < 0.15$; *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$; significance of pseudo-log-likelihoods based on Wald's $\chi^2$.
Note: Estimated coefficients with employee clustered standard errors below in parentheses.

Table A2. Average marginal gender effects (male = 1) for different levels of *sleeplim*.

| | Marginal gender effect, *M* (*SD*) | | | |
|---|---|---|---|---|
| Model | *sleeplim* = 1 | *sleeplim* = 2 | *sleeplim* = 3 | *sleeplim* = 4 |
| 3 | 0.125* | 0.011 | −0.482* | −0.060* |
| | (0.071) | (0.012) | (0.026) | (0.035) |
| 4 | 0.123* | 0.009 | −0.470* | −0.059* |
| | (0.072) | (0.012) | (0.027) | (0.036) |
| 5 | 0.133¥ | 0.013 | −0.050* | −0.065¥ |
| | (0.084) | (0.015) | (0.028) | (0.041) |
| 6 | 0.131¥ | 0.014 | −0.050* | −0.064¥ |
| | (0.083) | (0.016) | (0.028) | (0.042) |

¥$p < 0.15$; *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

# Appendix 2

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ARTICLE

# Does chronotype restrict the employment options of creative R&D professionals?

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**ABSTRACT**

How circadian rhythms affect socio-economic behaviour is little explored but is a promising area of research that could suggest considerable changes in policy making, social norms and individual decision making. This article presents a pilot study of perceived restrictions that sleep patterns set on the employment options of creative research and development professionals. The study is based on ordered probit and ordinary least squares regression modelling on a sample of 153 creative R&D employees from Estonia, with chronotype, sleep duration and various individual and work characteristics as explanatory variables. We find that evening type individuals and those who sleep more hours feel that sleep restricts their work options more than other employees do. Given that there is some genetic background to both morning-evening preference and sleep hours and they are therefore difficult to change, individuals of different chronotypes and with different sleep behaviour may not have equal options in finding employment in creative R&D work.

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## Introduction

Individuals can be categorised by their inherent circadian rhythms as morning type, neither type or evening type, but all types are often expected to follow similar working schedules. Past research suggests that while 60 per cent of people are neither type, roughly 40 per cent are either morning type or evening type (Adan et al. 2012). This motivates us to investigate in this exploratory pilot study whether the morningness-eveningness type of an individual limits their employment options. Our study draws on a sample of creative research and development employees, who form a distinct group of employees whose work results depend directly on their individual creative abilities and mood, these in turn being dependent on how alert and rested the employee is.

Employability is the likelihood of an individual gaining employment, or whether they become more employable the more they can fit the different demands of jobs (Chan 2000). A wide range of literature (see, e.g. Pulakos et al. 2000; Hall 2002; Fugate et al. 2004) suggests that success in a highly competitive labour market with ever-changing job demands requires

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employees to adapt to the changing environment and manage the changes both in themselves and in the context of their employment. The sleep habits of employees can be one feature that they need to adjust if they want to increase their employability, and we hypothesise that not adjusting those patterns may lead to limited employability.

Recent research suggests that circadian rhythms have a genetic background (Kalmbach et al. 2017; cf. works by 2017 Nobel prize recipients J. Hall, M. Rosbash and M. Young), while various inherent and environmental characteristics may also make a significant contribution to chronotype development (Kerkhof 1985; Adan et al. 2012). Morningness-eveningness appears to depend to some extent on age and related sleep habits, especially among the middle aged (Carrier et al. 1997; Taillard et al. 1999). Past research (Kerkhof and Van Dongen 1996; has demonstrated that morningness-eveningness and related time use preferences and behaviours result from a phase difference in the endogenous circadian clock. Previous studies show that evening-type employees sleep fewer hours than the morning types (Ishihara et al. 1988) and they are more likely to have worse general health (Paine et al. 2006). Evening types have been associated with more frequent psychological and psychosomatic disturbances (Randler 2008) and with depression (Merikanto et al. 2013).

Past research has documented a link between genetic factors and sleep duration (Utge et al. 2011; Goel 2017). While a growing number of studies suggest an association between the duration of sleep and employment (Antillon et al. 2014; Ásgeirsdóttir and Ólafsson 2015) and income level (Biddle and Hamermesh 1990; Grandner et al. 2010; Patel et al. 2010; Ásgeirsdóttir and Zoega 2011; Sedigh et al. 2017), there are no known studies on the relationship between morningness-eveningness and employment. Our pilot study seeks to contribute to investigation of that matter while still leaving room for further studies to follow on larger samples from different countries and job types.

## Data and methods

### *Study design*

The study is based on an online survey consisting of questions on work arrangements, work outcomes, sleepiness, sleep regimen, tiredness, health and some socio-demographic characteristics. We also asked the respondents for their name, age, gender, education and job details. The research project was approved by the Tallinn Medical Research Ethics Committee on 9 February 2015 by decision No. 894 and informed consent was obtained from all the respondents. The survey was conducted in two waves in spring-summer 2015 and winter 2016.

### *Sample*

The sample was compiled from the 2012 Statistics Estonia data on R&D employees. The target category for this study of creative employees is the category “researchers” in the Statistics Estonia classification of R&D employees, while the categories “technicians” and “supporting staff” are excluded. There were an average of 4.4 thousand full time equivalent creative R&D employees in the category “researchers” in Estonia in 2010–2014.

We have excluded from that population the 3.4 thousand or so employees working in higher education and healthcare, and those employed at microentities and research institutes with fewer than 15 creative R&D employees. This is because the teaching schedules in higher education, the appointments and procedures at medical institutions, and the working practices at microentities mean that their work arrangements are quite specific and may therefore interfere with the work, sleep, health and leisure time decisions that our project is targeted at. This leaves the population of creative R&D employees of interest for our study at approximately 1.0 thousand. Those employees work for 23 Estonian employers in both the private and public sectors, and they comprise applied researchers, product developers, IT developers and other creative R&D employees at private R&D companies, banks and technology and IT companies, and at public research institutes. All of these employers were invited to participate in this study, and 11 employers, or 48%, accepted the invitation. All the 807 employees from these 11 organisations were invited to participate, and 287 of them agreed to do so. In total 217 employees completed the survey in at least one of the two waves, giving an overall response rate of 76% of all those who had agreed to participate.

Of the 217 participants, 34 appeared in both the first and second waves of the survey. We performed Mann–Whitney U tests (Mann and Whitney 1947) to establish the statistical significance of the differences between the two waves in how sleep was perceived to restrict work options by the recurring respondents (cf Jankowski 2017), and we found these differences to be statistically insignificant. Because of this we have pooled the data from the two waves of the survey for the regression analysis and we selected randomly which of the two responses from the 34 recurring participants to use.

Additional eliminations from the sample of unique participants were made because of logical inconsistencies in the responses or because the respondent was identified from certain control questions incorporated in the survey questionnaire as not being sufficiently engaged in R&D for their employer. After all these exclusions the final sample consists of 153 employees, which equals 53% of those who agreed to participate in the survey. Of these 153 employees, 79% work in the private sector, with 35 in the technology industry, 21 in IT, 43 in the product or IT development units at banks, and 22 in R&D companies. Public R&D institutes employ 21% of the participants. Given that the final sample was not selected randomly from the total population of interest, we have weighted the observations in the sample to match it with the population of interest for the employer's area of activity and the employee's gender. As the Statistics Estonia dataset tells us the gender split of the employees and the distribution of the employers by their area of activity in the total population of around 1.0 thousand creative R&D employees of interest for our study, we have assigned a weight to each observation in our final sample to reflect the gender and area of activity characteristics of the observation so that the gender distribution of employees and area of activity distribution of the employers in the weighted sample matches the population of interest.

### *Dependent and explanatory variables*

We are interested in how much employees feel that their chronotype sets constraints on their employment. We asked the respondents to answer the question "To what extent do you feel that your sleep cycle limits or has limited your work options?" on a 5-level Likert-type scale ranging from "Not at all" = 0 to "Totally" = 5, which gives the dependent variable *restriction*.

The selection of independent variables is primarily derived from the previous literature. The score of the Reduced Morningness-Eveningness Questionnaire (*meq*; see Adan and Almirall 1991) reflects the circadian rhythm of the employee. Average sleep hours captures actual daily sleep patterns. The respondent's age, their gender, whether they live alone, how many children younger than school age they have and their level of education have been incorporated as key control variables for socio-demographic characteristics, while the *phealth* variable controls for the general health of the employee. The creative intensity desired for work is another explanatory variable that seeks to capture the creative nature of the work that the employee prefers. The dependent and explanatory variables are outlined in Table 1 and the pairwise correlation matrix of the variables is presented in the Appendix.

We used Stata version 14 (StataCorp, USA) for the Ordinary Least Squares (OLS) estimations with *restriction* as a continuous variable and ordered probit maximum likelihood estimations with *restriction* as an ordered discrete category, incorporating the explanatory variables outlined in Table 1.

## Results

The results of the OLS (Models 1 and 2) and ordered probit (Models 3 and 4) regression analysis are presented in Table 2 along with the Shorrocks-Shapely decomposition (Shorrocks 1982) of $R^2$ (OLS Model 1) and pseudo-$R^2$ (ordered probit Model 3). The ordered probit estimations provide an alternative approach to the OLS results and a robustness check for them, given that the dependent variable has skewed and non-normal patterns of distribution (as can be seen from Table 1). While Models 1 and 3 incorporate *meq* and *sleephours* as individual explanatory variables, Models 2 and 4 provide an alternative view with the interaction terms of *meq* and *sleephours*. However the $R^2$ of the OLS Model 1 is higher than that of Model 2, and the pseudo-log-likelihood of the ordered probit Model 3 is lower in absolute terms than that of Model 4, suggesting that Models 1 and 3 outperform Models 2 and 4.

We find from both of the Models 1 and 3 that morning-evening preference is an important driver of the perceived restrictions that the sleep regimen puts on employment (see Table 2). The non-parametric Mann–Whitney U test (Mann and Whitney 1947) that does not assume normal distribution shows that at the 95% confidence level ($p$ = 0.05) there is a statistically significant difference between evening types (*meq*≤ 11 – moderately to definitely evening type) and morning types (*meq*≥ 18 – moderately to definitely morning type) in that perception. Evening-type individuals expressed a stronger perception that their sleep regimen limits or has limited their employment opportunities than morning types did. Figure 1 illustrates the levels of an individual feeling that their sleep regimen has limited their work options.

**Table 1.** Model variables (mean and standard deviation shown for continuous and ordered variables; percentage of respondents shown for binary and categorical variables).

| Variable | Description | All: Mean/% (Std. Dev.) 153 (100%) | Men: Mean/% (Std. Dev.) 87 (57%) | Women: Mean/% (Std. Dev.) 66 (43%) |
|---|---|---|---|---|
| **Dependent** | | | | |
| Restriction | To what extent do you feel that your sleep cycle limits or has limited your work options? | | | |
| | "Not at all" (= 1) | 67% | 64% | 70% |
| | "To a small extent" (= 2) | 24% | 24% | 24% |
| | "Somewhat" (= 3) | 7% | 9% | 3% |
| | "To a large extent" (= 4) | 3% | 2% | 3% |
| **Explanatory** | | | | |
| meq | Reduced Morningness-Eveningness Questionnaire (Adan and Almirall 1991) score, 1…25 scale ranging from "Definitely an evening type" to "Definitely a morning type" | 14.73 (3.53) | 14.98 (3.57) | 14.39 (3.49) |
| Sleephours | Employee reported average sleeping hours per day on the scale: | | | |
| | "Less than 6 h" (= 1, base) | 7% | 6% | 8% |
| | "6–6.9 h" (= 2) | 50% | 49% | 50% |
| | "7–7.9 h" (= 3) | 38% | 39% | 36% |
| | "8–8.9 h" (= 4) | 6% | 6% | 6% |
| | "at least 9 h" (= 5, none in the sample) | 0% | 0% | 0% |
| Age | Age in years | 38.76 (11.51) | 37.72 (12.19) | 40.12 (10.48) |
| Gender | Male (= 1) or female (= 0) | 57% | 100% | 100% |
| Alone | The employee lives alone (= 1) or does not (= 0) | 25% | 24% | 26% |
| Children | Employee-reported number of children younger than school age living together with the employee | 0.38 (0.66) | 0.40 (0.71) | 0.35 (0.59) |
| Phealth | First principal component score of general health (with overall Kaiser-Meyer-Olkin measure of sampling adequacy of the factor 0.6), comprising: | 0.00 (1.41) | 0.11 (1.39) | −0.15 (1.45) |
| | (1) "Do you have high blood pressure or have you ever used medicine for high blood pressure?" (yes = 1) | 20% | 22% | 18% |
| | (2) "Do you suffer or have you suffered from illnesses that significantly affect your mental fatigue?" (5-level Likert type scale, "Never" = 1, "Often" = 5) | 1.71 (0.95) | 1.75 (0.97) | 1.67 (0.93) |
| | (3) "Does any illness or injury interrupt you while doing your daily job?" (5-level Likert type scale, "No obstacles" = 1, "Not able to work" = 5) | 1.58 (0.73) | 1.57 (0.77) | 1.58 (0.68) |
| | (4) "How many workdays have you been absent from work due to illness or medical examination in the past 12 months?"(5-level scale, "None" = 1, "100–365 days" = 5) | 1.75 (0.72) | 1.77 (0.69) | 1.71 (0.76) |
| | (5) Body-Mass Index (continuous) | 24.65 (3.90) | 25.35 (3.11) | 23.72 (4.61) |
| Education | Years of education starting from primary education | 16.58 (2.65) | 15.97 (2.85) | 17.39 (2.14) |
| Creative | Share of creative work desired by the employee in total working time of the employee (%) | 71.70 (20.49) | 71.18 (21.03) | 72.38 (19.90) |

Hours of sleep are strongly related to perceived constraints on work options caused by sleep patterns. The more hours an individual sleeps each night, the more they feel the limitations that their sleep regimen sets on job selection. This relationship is

**Table 2.** OLS and ordered probit estimates of *restriction*.

| | Model 1 | | Model 2 | Model 3 | | Model 4 |
|---|---|---|---|---|---|---|
| Estimation | OLS | $R^2$ decomp.‡ | OLS | Ordered probit | Pseudo-$R^2$ decomp. ‡ | Ordered probit |
| meq | −0.040* (0.02) | 0.036 | | −0.075* (0.03) | 0.018 | |
| Sleephours | 0.232* (0.10) | 0.028 | | 0.477* (0.20) | 0.016 | |
| Sleephours = 1 # meq | | | −0.043 (0.04) | | | −0.072 (0.07) |
| Sleephours = 2 # meq | | | −0.043* (0.02) | | | −0.091* (0.04) |
| Sleephours = 3 # meq | | | −0.026 (0.02) | | | −0.048 (0.03) |
| Sleephours = 4 # meq | | | −0.015 (0.02) | | | −0.031 (0.03) |
| age | −0.011 (0.01) | 0.038 | −0.012 (0.01) | −0.026 (0.02) | 0.026 | −0.028 (0.02) |
| Gender (Male = 1) | 0.035 (0.09) | 0.000 | 0.038 (0.09) | 0.013 (0.18) | 0.002 | 0.032 (0.18) |
| Alone (Living alone = 1) | −0.178 (0.11) | 0.000 | −0.198* (0.10) | −0.477 (0.27) | 0.001 | −0.550* (0.25) |
| Children | −0.051 (0.09) | 0.000 | −0.077 (0.10) | −0.128 (0.19) | 0.000 | −0.200 (0.20) |
| Phealth (1st PC) | 0.113* (0.05) | 0.035 | 0.104 (0.06) | 0.190* (0.09) | 0.018 | 0.169* (0.09) |
| Education | 0.017 (0.02) | 0.001 | 0.020 (0.02) | 0.039 (0.04) | 0.001 | 0.052 (0.04) |
| Creative | −0.004 (0.00) | 0.003 | −0.004 (0.00) | −0.010 (0.01) | 0.003 | −0.009 (0.01) |
| Constant | 1.901** (0.46) | | 2.360** (0.39) | | | |
| $R^2$/pseudo-$R^2$ | 0.189 | | 0.178 | 0.132 | | 0.130 |
| Pseudo-log-likelihood | | | | −118.9 | | −119.1 |
| *F*-test/*p* Wald's chi$^2$ | ** | | ** | ** | | ** |
| *N* | 153 | | 153 | 153 | | 153 |

*Notes: *p ≤ 0.05, **p ≤ 0.01; ‡Shorrocks-Shapely decomposition of $R^2$ (Model 1) and pseudo-$R^2$ (Model 3)*

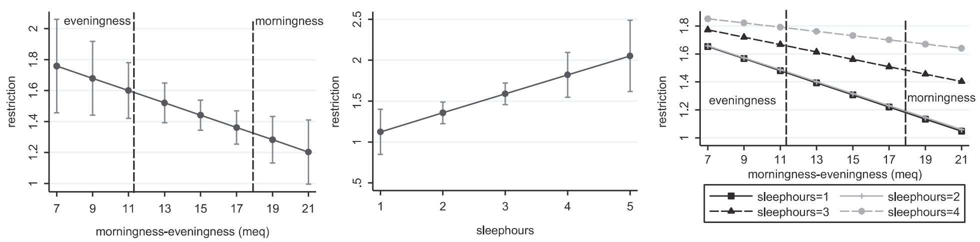


**Figure 1.** The levels of an individual perceiving that their sleep regimen limits their work options for different levels of morningness-eveningness (left) and sleep hours (middle) and the combination of the two (right) (adjusted estimates at means with 90% confidence intervals).

illustrated in Figure 1 for each category of *sleephours*, and it is evident from both the OLS and ordered probit estimates in Models 1 and 3.

General health is another robust predictor of the perception of employment limitations related to sleep. The better the general health of the employee is, the lower the probability that those restrictions are felt.

## Discussion

The link identified between individual chronotype and the availability of work options is a novel result. That evening-type individuals feel that their sleep regimen sets significantly higher limitations on their employment options than morning types do hints that certain jobs with the standard nine-to-five work routine may remain difficult for the evening type people to access. As recent research (e.g. Kalmbach et al. 2017) suggests that circadian rhythms have some genetic background, a potential explanation is that it may be difficult for an individual to adjust their chronotype to align it with standard working hours, which in turn may narrow the job opportunities for that person. Unless the employer allows flexible working time without penalising it with a lower salary or otherwise adverse terms of employment, an evening type individual might not be able to take the job without making potentially large sacrifices in their sleeping time preferences. A study on the same sample data reveals that the creative work outcomes of both clearly evening types and clearly morning types are significantly greater than those of the neither types while evening type employees perceive with a significantly higher probability that work limits their sleep to a large extent (Hazak et al. 2017, Forthcoming), suggesting that the more intensely perceived limitations on the employment of evening types cannot be explained by their productivity being lower. Further studies are needed to confirm the relationship between an individual's chronotype and employment using larger samples from different countries and job types. The results of our exploratory pilot study point, however, to a societally important issue of evening type individuals potentially not having equal options in finding employment in creative R&D work because of their inherent circadian rhythms, which are hard to adjust to the prevailing regulations and social norms for the timing of work.

A possible explanation for the positive relationship between sleeping hours and the probability of the individual perceiving sleep-related constraints on their work options is that relatively long sleeping hours constrain the individual in their choice of job when the start or end time of work is not in alignment with their sleeping patterns, especially when there are fewer hours in the day that can be dedicated to work. This finding is in alignment with the theoretical arguments of the literature on the economics of sleep (e.g. Asgeirsdottir and Zoega 2011). The suggestion can be drawn from the growing literature on the genetic background of the duration of sleep (Utge et al. 2011; Goel 2017) and its linkages with chronotype (Ishihara et al. 1988) that sleeping hours may be hard for a person to adjust. This may limit the employment options of the individual as work with an inconvenient duration or timing would interfere with their natural sleeping patterns. Those who are not ready to make sacrifices in their sleeping time may thus feel constrained in their work options. These findings are overall in alignment with the arguments presented in the earlier literature (Antillon et al. 2014; Ásgeirsdóttir and Ólafsson 2015).

The control variables that exhibit a significant relationship with perceived constraints on employability related to sleep point in the expected directions, given the past research (Monk et al. 1994; Sedigh et al. 2017; Yadav et al. 2017). Employees living alone appear less constrained in their employability than are people with families, who have various family obligations and must obey the time use patterns and preferences of other family members, which can then affect their sleep. This finding is in line with another study on the same sample data (Hazak et al. 2016; Virkebau and Hazak 2017; Ruubel and Hazak 2018), which shows that people living alone are significantly less likely actually to use flexible working options than employees with families are. General health may have similar effects, as individuals with weaker general health may feel constrained in their work by their inability to meet the job requirements because of lost or otherwise anomalous sleep (see Lauderdale et al. 2016), and employers may not opt for employees with health issues when they are recruiting. Both these findings point to important policy issues, as the employment of people regardless of their health or family status is high on the political agenda. Sleep may be a potential mediator of limitations in employability driven both by health and by family status.

We acknowledge that the small size of the sample and the relatively low participation rate of employers and employees in the survey are limitations of our study, but we are quite confident that the results of the research are representative of creative R&D employees in Estonia because of the careful design of the study population as discussed above and the fully observed results. We note however that the share of employees who perceive their opportunities for work to be constrained by sleep factors is relatively small (see Table 1), which limits our ability to achieve strongly statistically significant results. Another limitation of the study is that the members of the target population could only be included in the sample if their employer agreed to take part in the study. Furthermore, there may be selection bias because of differences between those respondents who completed the survey and those who in the end did not. These selection biases are tackled by weighting the sample for the respondent's gender and the employer's area of activity in order to align the sample with the characteristics of the target population. Clustering standard errors by employer-gender interaction terms in the models further contributes to the identification of any unobserved dependencies in the clusters by employer and gender. It is not impossible though that there remain some selection biases, and expanded studies on different samples in other countries or jobs remains a promising avenue for research in the future.

## Conclusions

How circadian rhythms affect socio-economic decision-making is a promising area of research that could lead to considerable changes being made in policy making, social norms and individual behaviour. This article presents a pilot study on the constraints on employability that individuals perceive from their morning-evening preference. We find that evening type individuals and those who sleep more hours feel significantly more intensely that their sleep cycle restricts their work options. Given that there is some genetic background to both morning-evening preference and sleep hours and they are therefore difficult for the individual to change, individuals of different morningness-eveningness types and with different sleep patterns may not have equal options in finding employment in creative R&D work. However, this phenomenon would need to be confirmed by further research as our pilot study is based on a limited sample of 153 Estonian creative research and development employees. Consideration of individual characteristics in circadian rhythms and sleep preferences is important not only for achieving improvements in individual wellbeing but also for helping the labour market and human resources management function more fairly and efficiently.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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## References

Adan A, Almirall HH. 1991. Östberg morningness-eveningness questionnaire: a reduced scale. Pers Individ Dif. 12(3):241–253.

Adan A, Archer SN, Hidalgo MP, Di Milia L, Natale V, Randler C. 2012. Circadian typology: a comprehensive review. Chronobiol Int. 29:1153–1175.

Ásgeirsdóttir TL, Zoega G. 2011. On the economics of sleeping. Mind Soc. 10(2):149.

Ásgeirsdóttir TL, Ólafsson SP. 2015. An empirical analysis of the demand for sleep: evidence from the American time use survey. Econ Hum Biol. 19:265–274.

Antillon M, Lauderdale DS, Mullahy J. 2014. Sleep behavior and unemployment conditions. Econ Hum Biol. 14:22–32.

Biddle J, Hamermesh D. 1990. Sleep and the allocation of time. J Polit Economy. 98(5):922–943.

Carrier J, Monk TH, Buysse DJ, Kupfer DJ. 1997. Sleep and morningness-eveningness in the middle years of life (20-59 y). J Sleep Res. 6:230–237.

Chan D. 2000. Understanding adaptation to changes in the work environment: integrating individual difference and learning perspectives. In: Ferris GR, editor. Research in personnel and human resources management. Vol. 18, p. 1–42. Greenwich, CN: JAI Press.

Fugate M, Kinicki AJ, Ashforth BE. 2004. Employability: a psycho-social construct, its dimensions, and applications. J Vocat Behav. 65(1):14–38.

Goel N. 2017. Genetic markers of sleep and sleepiness. Sleep Med Clin. 12(3):289–299.

Grandner MA, Patel NP, Gehrman PR, Xie D, Sha D, Weaver T, Gooneratne N. 2010. Who gets the best sleep? Ethnic and socioeconomic factors related to sleep complaints. Sleep Med. 11 (5):470–478.

Hall DT. 2002. Careers in and out of organizations. Thousand Oaks (CA): Sage.
Hazak A, Männasoo K, Virkebau M. 2017. Effects of work arrangements on creative R&D work outcomes. East Europ Econ. 55(6):500–521.
Hazak A, Sõõru E, Hein H, Männasoo K. Forthcoming. Effects of work arrangements on the sleep regimen of creative R&D employees. Int J Occup Saf Ergon. 2018.
Hazak A, Tint P, Virkebau M, Pille V, Tuulik V, Sõõru E. 2016. Social innovation potential in working arrangements of R&D employees: repeated employee survey from Estonia. 2016 IEEE International Conference on Emerging Technologies and Innovative Business Practices for the Transformation of Societies (EmergiTech). Balaclava, Mauritius: IEEE. p. 210–213.
Ishihara K, Miyake S, Miyasita A, Miyata Y. 1988. Comparisons of sleep-wake habits of morning and evening types in Japanese worker sample. J Hum Ergol. 17:111–118.
Jankowski KS. 2017. Morningness-eveningness and seasonality. Biol Rhythm Res. 48(3):331–342.
Kalmbach DA, Schneider LD, Cheung J, Bertrand SJ, Kariharan T, Pack AI, Gehrman PR. 2017. Genetic basis of chronotype in humans: insights from three landmark GWAS. Sleep. 40(2): zsw048. https://doi.org/10.1093/sleep/zsw048.
Kerkhof GA. 1985. Inter-individual differences in the human circadian system: a review. Biol Psychol. 20:83–112.
Kerkhof GA, Van Dongen HP. 1996. Morning-type and evening type individuals differ in the phase position of their endogenous circadian oscillator. Neurosci Lett. 218:153–156.
Lauderdale DS, Chen JH, Kurina LM, Waite LJ, Thisted RA. 2016. Sleep duration and health among older adults: associations vary by how sleep is measured. J Epidemiol Community Health. 70 (4):361–366.
Mann HB, Whitney DR. 1947. On a test of whether one of two random variables is stochastically larger than the other. Ann Math Stat. 18(1):50–60. doi:10.1214/aoms/1177730491
Merikanto, I, Lahti, T, Kronholm, E, Peltonen M, Laatikainen T, Vartiainen E, Salomaa V, Partonen, T. 2013. Evening types are prone to depression. Chronobiol Int. 30(5):719–725.
Monk TH, Petrie SR, Hayes AJ, Kupfer DJ. 1994. Regularity of daily life in relation to personality, age, gender, sleep quality and circadian rhythms. J Sleep Res. 3:196–205.
Paine SJ, Gander PH, Travier N. 2006. The epidemiology of morningness/eveningness: influence of age, gender, ethnicity, and socioeconomic factors in adults (30-49 years). J Biol Rhythms. 21 (1):68–76.
Patel NP, Grandner MA, Xie D, Branas CC, Gooneratne N. 2010. "Sleep disparity" in the population: poor sleep quality is strongly associated with poverty and ethnicity. BMC Public Health. 10(1):475.
Pulakos ED, Arad S, Donovan MA, Plamondon KE. 2000. Adaptability in the workplace: development of a taxonomy of adaptive performance. J Appl Psychol. 85:612–624.
Randler C. 2008. Morningness-eveningness and satisfaction with life. Soc Indic Res. 86:297–302.
Ruubel R, Hazak A. 2018. Disparities in knowledge employees' actual, contractual and desired working schedules. Knowl Manag. 18(1):17–30. doi:10.18848/2327-7998/CGP/v18i01/17-30
Sedigh GI, Devlin RA, Grenier G. 2017. Revisiting the relationship between wages and sleep duration: the role of insomnia. Econ Hum Biol. 24:125–139.
Shorrocks A. 1982. Inequality decomposition by factor components. Econometrica. 50(1):193–211.
Taillard J, Philp P, Bioulac B. 1999. Morningness/eveningness and the need for sleep. J Sleep Res. 8:291–295.
Utge S, Kronholm E, Partonen T. 2011. Shared genetic background for regulation of mood and sleep: association of GRIA3 with sleep duration in healthy finnish women. Sleep. 34 (10):1309–1316.
Virkebau M, Hazak A. 2017. What type of research and development employees use flextime? Int J Organizational Diversity. 17(2):1–9. doi:10.18848/2328-6261/CGP/v17i02/1-9
Yadav A, Verma P, Singh S. 2017. Going beyond the limits: effect of clock disruption on human health. Biol Rhythm Res. 48(5):693–700.

## Appendix

**Pairwise linear correlations** (correlation coefficients for each pair of variables the with *p* values below)

| | Restriction | meq | Sleephours | Age | Gender | Alone | Children | Phealth | Education |
|---|---|---|---|---|---|---|---|---|---|
| meq | −0.2081 | | | | | | | | |
| | 0.0098 | | | | | | | | |
| Sleephours | 0.1556 | 0.1350 | | | | | | | |
| | 0.0548 | 0.0962 | | | | | | | |
| Age | −0.2167 | 0.3030 | −0.0584 | | | | | | |
| | 0.0071 | 0.0001 | 0.4733 | | | | | | |
| Gender | 0.0679 | 0.0820 | 0.0276 | −0.1035 | | | | | |
| | 0.4042 | 0.3137 | 0.7347 | 0.2031 | | | | | |
| Alone | −0.0028 | −0.0110 | −0.0515 | −0.0657 | −0.0186 | | | | |
| | 0.9722 | 0.8924 | 0.5272 | 0.4199 | 0.8198 | | | | |
| Children | −0.0157 | −0.0087 | −0.1419 | −0.0893 | 0.0406 | −0.2857 | | | |
| | 0.8469 | 0.9150 | 0.0802 | 0.2723 | 0.6185 | 0.0003 | | | |
| Phealth | 0.1646 | −0.0192 | −0.0779 | 0.2039 | 0.0910 | 0.0022 | −0.0668 | | |
| | 0.0420 | 0.8133 | 0.3383 | 0.0115 | 0.2635 | 0.9784 | 0.4120 | | |
| Education | −0.0544 | −0.0039 | 0.0056 | 0.2972 | −0.2671 | −0.0349 | −0.1493 | −0.0167 | |
| | 0.5039 | 0.9618 | 0.9448 | 0.0002 | 0.0008 | 0.6687 | 0.0655 | 0.8378 | |
| Creative | −0.0701 | −0.0368 | −0.0834 | 0.1921 | −0.0290 | 0.1966 | −0.0855 | 0.0333 | 0.2701 |
| | 0.3893 | 0.6520 | 0.3053 | 0.0174 | 0.7222 | 0.0149 | 0.2932 | 0.6829 | 0.0007 |

# Appendix 3

**Invention**

Invention: A method and device for personalized pulse oximetry; Owners: RES-MEDICA OÜ, ELIKO Tehnoloogia Arenduskeskus OÜ; Authors: Erve Sõõru, Mart Min, Paul Annus, Raul Land; Priority number: US 61/771,903; Priority date: 3.03.2013.

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| **Title of Invention:** | A method and device for personalized pulse oximetry |
| **First Named Inventor/Applicant Name:** | Erve SÕÕRU |
| **Customer Number:** | 11351 |
| **Filer:** | MARGUS SARAP |
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## A method and device for personalized pulse oximetry

TECHNICAL FIELD

A method and device are provided for personalized pulse oximetry of a patient for investigation of the sleep apnoea syndrome, wherein wearable pulse oximeter supplied for the patient for home use sleep study is able to identify if the device is used by a third person during the period.

BACKGROUND ART

Pulse oximetry plays an essential role in early detection of hypoxaemia and level of oxyhaemoglobin desaturation during night. Although pulse oximetry has become a basic standard of care in the developed world, its availability and use is severely limited in low-resource settings. Barriers preventing the uptake of pulse oximetry need to be identified and overcome so that oximetry becomes available to clinicians and patients throughout the world [1].

Wearing a pulse oximetry for one or two nights (or even for longer period) and then having a physician evaluate the stored sleep respiration patterns would provide an easy way of obtaining a diagnosis. Since sleep apnoea often remains undetected, circummission pulse oximetry might become an easy and cost saving screening method in the near future [2].

There are several diagnostic methods for evaluate sleep disorders. Full polysomnography is known as gold standard diagnostic method, also respiratory polygraphy and other limited sleep studies, as multiple sleep latency test, pupillography, driving simulation test, and different questionnaires. Pulse oximetry sensor plays an essential role in most sleep studies, especially in the studies evaluating sleep disordered breathing.

Role of identification sensors has not been shown in previous studies yet. There are no methods for identification during sleep studies till today.

Untreated obstructive sleep apnoea increases the risk of having a car crash two-fold. In addition, the severity of sleep-disordered breathing, degree of oxygen desaturation, self-reported sleepiness and body mass index increase the risk of crash in obstructive sleep apnoea patients. Continuous positive airway pressure (CPAP) reduces the risk of car crash. The data are insufficient for other forms of treatment to date [3].

All methods for evaluating sleep disorders in first line are very expensive. Therefore there is need for a method and device with wide potential of use and cheaper. In addition there is a need for use these diagnostic tools in out-patients investigations with identified personalized data (i.e. for obtaining a Driving Licence for truck drivers).

Wearable pulse oximetry has been well developed over the past decades. Basic principle is based on absorption difference of at least two, red and infrared, optical signals passing through the patient's body. Signal strength at receiver side from of each light source depends on colour and thickness of the body tissue, the sensor placement, the intensity of the light sources, and the absorption of the arterial and venous blood (including the time varying effects of the pulse). The sensor for the measurement of this physical characteristic contains two LEDs: one emits visible red light (for example 660 nm) and the other infrared light (for example 940 nm). When passing through the tissue, the emitted light is partially absorbed by blood depending on the concentration of oxygen bound on haemoglobin. Secondly, as the volume of arterial blood changes with each pulse, the light signal obtained by a photo-detector has a pulsatile component which can be exploited for the measurement of pulse rate. The oximeter processes these signals, separating the time invariant parameters (tissue thickness, skin colour, light intensity, and venous blood) from the time variant parameters (arterial volume and $SpO_2$) to identify the pulse rate and calculate oxygen saturation. Oxygen saturation calculations can be performed because oxygen saturated blood absorbs less red light than oxygen depleted blood. As an example, the devices by Nonin Medical Inc. (http://www.nonin.com) use clinically-proven PureSAT pulse oximetry technology. It utilizes intelligent pulse-by-pulse filtering to provide precise oximetry measurements — even in the presence of motion, low perfusion or other challenging conditions. By reading the entire plethysmographic waveform, PureSAT signal processing prefilters the pulse signals to remove undesirable signals and advanced algorithms then separate the pulse signals from artifact and interference — leaving only the true pulse. And with smart averaging technology, PureSAT automatically adjusts to each patient's condition to provide fast and reliable readings. Lately devices have been improved by adding more light sources. Typical example would be pulse oximeter by Masimo Corporation (http://www.masimo.com), which uses more than 7 wavelengths of light to acquire blood constituent data based on light absorption together with advanced signal processing algorithms and unique adaptive filters (light spectroscopy). Parameter to acquire, according to their datasheet, includes Total Hemoglobin (SpHb®), Oxygen Content (SpOC™), Carboxyhemoglobin (SpCO®), Methemoglobin (SpMet®), Pleth Variability Index (PVI®), Oxygen Saturation (SpO2), Pulse Rate (PR), and Perfusion Index (PI).

These and similar devices by many other manufacturers can be used both in clinical conditions and outside the hospital to acquire pulse rate and $SpO_2$ data.

Since its introduction in the 1970s, pulse oximetry has become a common and valuable clinical tool. The use of recording continuous oximetry overnight is a more recent application of this technology. The gold standard for the assessment of sleep quality and sleep disordered breathing is polysomnography. However, limited channel studies such as pulse oximetry may still provide useful data. As with all tests, it is critical to understand the indications for pulse oximetry, what the instrument measures and reports, its limitations and how to interpret results. Sleep and sleep disorders have gained importance in the medical field. One of the simplest methods used in night medicine for evaluating obstructive sleep apnoea syndrome (OSAS) is the continuous recording of oxygen saturation (SpO2) during sleep with pulse oximeter. Sleep disorders can have severe impact on daytime performance of the patient. Symptoms such as daytime hyper sleepiness, fatigue, indisposition, lack of attention, reduced memory capacity, depression, lower reflexes and the sense of loss of organizational capacity are all common complaints. They can result in disastrous outcome for the person or persons around him in cases when health and wellbeing depends on alertness to sudden dangers. Some of the occupations which require closer attention are rescue workers, law enforcement officers, soldiers, construction workers, car drivers and others. It would be highly beneficial to validate their health status prior work permission. Validation in clinical surroundings is cumbersome and expensive. Usage of wearable pulse oximeters enables generally sleep study at home during the normal night sleep. Later method however suffers from the anonymity of the data. It is not possible to verify if the device is used by the person required to undergo the study in order to obtain the work permit.

Therefore addition of some biometric verification the pulse oximetry device is justified discouraging falsification of the study results.

Biometric identification refers to identifying an individual based on his or her distinguishing physiological and/or behavioural characteristics (biometric identifiers) [4]. It provides a better solution for the increased security requirements of our information society than traditional identification methods such as passwords and PINs. As biometric sensors become less expensive and miniaturized, and as the public realizes that biometrics is actually an effective strategy for protection of privacy and from fraud, this technology is likely to be used in almost every transaction needing authentication of personal identity [5]. Typical biometric identifiers include results from facial image analysis, facial thermograms, fingerprints, limb geometry, retinal pattern, and handwriting and speech analysis [5]. Method for wearable sensors to recognize a person using bioimpedance can have balanced accuracy of 85% [6]. When combined with wrist circumference measurements the method is 90% accurate at recognizing users. In addition to electrical bioimpedance also optical impedance (optical properties of human skin) can be used for identification purposes. This hardware method may be regarded not only as a liveness detection mechanism but also as an individual biometric system with an inherent liveness capability. Living human skin has certain unique optical characteristics due to its chemical composition, which predominately affects optical absorbance properties, as well as its multi-layered structure, which has a significant effect on the resulting scattering properties [7, 8].

While both pulse oximetry devices and biometric identification principles are known for a longer period already, the physical methods and devices for personification of the obtained oximetric data in order to provide authenticated data acquisition are not known.

## SUMMARY OF INVENTION

A method and device are provided for personalized pulse oximetry of a patient for investigation of the sleep apnoea syndrome, wherein wearable pulse oximeter supplied for the patient for home use sleep study is able to identify if the device is used by a third person during the period.

Wearable pulse oximetry device is amended with suitable biometric authentication unit discouraging falsification of study results. Biometric authentication is achieved by means of physiological biometry.

In addition, the authors of the present technical solution - the wearable pulse oximetry device – propose to use it for diagnosing of obstructive sleep apnoea among vehicle drivers and other executors of mission critical tasks by using pulse oximetry involving a secure identification of the patient.

The benefits of the wearable pulse oximetry device and method are:

1. Excluding the possibility that the survey is conducted with another person;

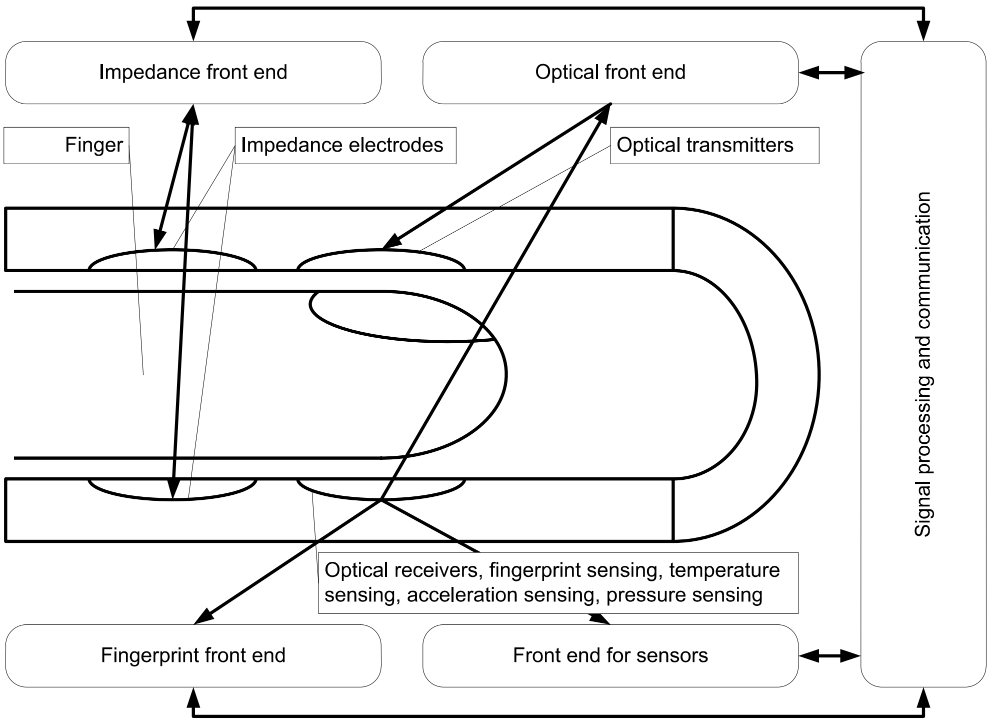
2. Considerably cheaper first line investigation method compared with polysomnography (or any other multi-channel sleep study);

3. Wide potential of use for detecting sleep disorders and their consequences.

4. Possibility to combine with the vehicle driver's medical certificate when applying for a driver's licence for work in the future as a simple and accessible method;

5. The results of the study are of high specificity and sensitivity compared to full polysomnography or respiratory polygraphy.

## BRIEF DESCRIPTION OF THE DRAWINGS




DETAILED DESCRIPTION OF THE EMBODIMENT

The method for identifying vital parameters of the wearer for evaluating sleep disorders during sleep comprises the steps of:

- determining the pulse rate and
- calculation of oxygen saturation with analysis of vital biological data of the wearer. Whereas the data analysed for biometric and sleep study reasons can include temperature, thermal and optical scan of fingerprint, electrical impedance and optical impedance (time invariant parameters usually disregarded in pulse oximetry) of the body/finger tissue, acceleration, pressure, temperature, and geometric measures (and/or volumes);
- comparison the analysed data with the data recorded in the memory of the device and
- in case of difference generating the warning signal (light and/or sound)

- recording said warning signal in the memory with anti-tamper protection of the device.

The device for personalized pulse oximetry of a patient for investigation of the sleep apnoea syndrome according to the present invention comprises a wearable pulse oximeter and sleep study sensors comprising a unit for identifying identity of the wearer, a signal processing unit, and a control unit, wherein an output recording of the pulse oximeter is tied to identification data of the wearer. The unit for identifying identity of the wearer comprises the means for extracting the bioimpedance data of the wearer. The means for extracting the electrical bioimpedance data of the wearer are for example impedance electrodes arranged inside of the wearable pulse oximeter so that when said pulse oximeter is placed to the finger for obtaining biological data of the wearer one set of impedance electrodes will be in one side of the finger and second set of impedance electrodes will be in other side of the finger for obtaining bioimpedance data of the wearer to identify the wearer. In alternative embodiments said means comprises the fingerprint sensors arranged inside of the wearable pulse oximeter so that when the oximeter is placed to the finger the fingerprint sensor will be in contact with fingerprint for reading wearer fingerprint image into signal processing unit. At the same time the second sensor (for example optical transmitter) which is arranged inside the oximeter remains in the other side of the wearer finger and transmits bioimpedance data, fingerprint data, temperature, pressure, acceleration etc data to the signal processing unit where data for identifying wearer are compared with corresponding data recorder in the memory with anti-tamper protection of the control unit. All sensors or transmitters arranged inside of the oximeter are connected with the signal processing and communication unit and control unit for transmitting biological data of the wearer to said signal processing unit and for receiving control signals from said control unit, for example command to switch on/off bioimpedance electrodes, fingerprint sensors, optical transmitter, temperature sensors, pressure sensors. Alternatively said unit comprises the means for identifying geometrical measures and/or volume of the wearer. In yet another alternative solution the unit for identifying identity of the wearer comprises all above-mentioned means or combination of thereof forming multi-biometric system where the parameters of the wearer are extracted. In such an embodiment the multi-biometric system integrates these unimodal systems sequentially, simultaneously, a combination thereof, or in series, which refer to sequential, parallel, hierarchical and serial integration modes, respectively.

In case of studying vital parameters of the person during the sleep the personalized pulse oximeter is placed to the finger of the person and all first reading of the biometric data of the wearer (bioimpedance data, fingerprint data etc) are obtained and thereafter recorded into the memory with anti-tamper protection of the control unit. Alternatively said data are obtained previously during the testing and thereafter recorded in the memory with anti-tamper protection of the oximeter by personalizing said oximeter to the wearer. The personalized oximeter will be handed out to the wearer and according to study plans the wearer puts the personalized oximeter to the finger. The control unit sends the control signal to the sensors to determine whether the oximeter is placed in the correct position to the finger. If the oximeter is placed wrongly (for example fingerprint sensor is not in the contact with fingerprint of finger) the control unit of the oximeter issues a warning signal so that the wearer can change the oximeter position. When the oximeter is placed correctly to the wearer finger the control unit send the signal to the sensors for obtaining personal biometric data of the wearer and when the signal returns compares obtained biometric data with the personalized data of the wearer recorded in the memory with anti-tamper protection. If the control unit finds differences of the analysed data said control unit generates the warning signal (light and/or sound) and records signal data to the memory with anti-tamper protection.

In alternative solutions the personalized oximeter can be equipped with a clock to record time of performed operations to the device memory.

To ensure the protection of the personal data the devise comprised the module for encrypting the wearer personal and biometric data to ensure its integrity.

**We claim:**

1. A method for identifying vital biological data of the wearer during sleep study, the method comprising steps of:

- determining the pulse rate and calculation of oxygen saturation together with analysis of vital biological data of the wearer, whereas the vital biological data to be analysed for biometric and sleep study reasons can include temperature, pressure, thermal, electrical and optical scan of fingerprint, electrical impedance and optical impedance (time invariant parameters usually disregarded in pulse oximetry) of the body tissue, acceleration, pressure, temperature, and geometric measures and/or volumes,
- comparison the analysed vital biological data with the vital biological data recorded in the memory with anti-tamper protection of the device.

2. The method according to claim 1, where the vital biological data of the wearer are extracted from the pulse oximeter’s optical signals passing through the body of the wearer.
3. The method according to claim 1, where the vital biological data parameters of the wearer are extracted from the bioimpedance data of the wearer.
4. The method according to claim 3, where the bioimpedance data of the wearer are extracted at different frequencies of electrical signals sequentially or simultaneously
5. The method according to claim 1, where the vital biological data of the wearer are extracted from the fingerprint sensors.
6. The method according to claims 1, where the vital biological data of the wearer are extracted from the geometrical measures and/or volumes.
7. The method according to claim 1, where the vital biological data of the wearer are extracted from the pressure sensor data.
8. The method according to claim 1, where the vital biological data of the wearer are extracted from the temperature sensor data.
9. The method according to claim 3, where the bioimpedance data of the wearer are extracted from the electrical capacitance sensor data.
10. The method according to claim 9, where the electrical capacitance sensor data are extracted at different frequencies of electrical signals sequentially or simultaneously.

11. The method according to claim 3, where the bioimpedance data of the wearer are extracted from the electrical conductivity sensor data.
12. The method according to claim 11, where the electrical conductivity sensor data are extracted at different frequencies of electrical signals sequentially or simultaneously.
13. The method according to claim 3, where bioimpedance data of the wearer are extracted from the electrical permittivity sensor data.
14. The method according to claim 13, where the electrical permittivity sensor data are extracted at different frequencies of electrical signals sequentially or simultaneously.
15. The method according to claim 1, where the vital biological data of the wearer are extracted from the accelerometer sensor data.
16. The method according to claim 1, where in case of difference when comparison the analysed data with the data recorded in the memory of the device the warning signal (light and/or sound) is generated and said warning signal is recorded in the memory with anti-tamper protection of the device.
17. The method according to claim 1 whereas the personal data and vital biological data of the wearer are encrypted to ensure the protection and integrity of said data.
18. A device for identifying vital biological data of the wearer comprising a pulse oximeter, unit for identifying identity of the wearer, signal processing unit, and a control unit, wherein an output recording of the pulse oximeter is tied to identification data of the wearer.
19. The device according to claim 18, wherein the vital biological data of the wearer are extracted from the pulse oximeter’s optical signals passing through the body of the wearer.
20. The device according to claim 18, wherein the vital biological data of the wearer are extracted from the bioimpedance data of the wearer.
21. The device according to claim 18, wherein the vital biological data of the wearer are extracted from the fingerprint sensors.

22. The device according to claim 18, wherein the vital biological data of the wearer are extracted from the geometrical measures and /or volumes.
23. The device according to claim 18-22, wherein vital biological data of the wearer are extracted in combination of methods according to the claims 2-17 composing multi-biometric system comprising and integrating the unimodal systems sequentially, simultaneously, a combination thereof, or in series, which refer to sequential, parallel, hierarchical and serial integration modes, respectively.
24. The device according to claim 18, wherein the vital biological data of the wearer are extracted according to the claims 19-23 and the data encryption unit is introduced to ensure data integrity.

**References:**


1. Lara, J.Herbert, Iain, H.Wilson. Pulse oximetry in low-resource settings. Breathe 2012; 9: 90-97.
2. Buschmann, J.P., Huang, J. New Ear Sensor for Mobile, Continuous and Long Term Pulse Oximetry. Conference of the IEEE EMBS, Buenos Aires, 2010.
3. Phillips, B. Morbidity and Mortality of sleep-disordered breathing: obstructive sleep apnoea and car crash. Breathe 2009; 6: 115-119.
4. Jain, A.K. Bolle, R. and Pankanti S. (eds.). Biometrics: Personal Identification in Networked Society. Kluwer, New York, 1999.
5. Jain, A., Hong, L., & Pankanti, S. (2000). "Biometric Identification". Communications of the ACM, 43(2), p. 91-98.
6. Cornelius, C., Sorber, J., Peterson, R., Skinner, J., Halter, R., Kotz, D. (2012), Who wears me? Bioimpedance as a passive biometric. HealthSec'12, Bellevue, WA.
7. Rowe, R.K.: Spoof Detection, In: Summer School for Advanced Studies on Biometrics for Secure Authentication, Alghero, Italy, 2008, p. 43.
8. Rowe, R.K.: A Multispectral Sensor for Fingerprint Spoof Detection, www.sensormag.com, January 2005.

PTO/SB/16 (11-08)
Approved for use through 05/31/2015. OMB 0651-0032
U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE


# Provisional Application for Patent Cover Sheet

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c)

## Inventor(s)

Inventor 1 — Remove

| Given Name | Middle Name | Family Name | City | State | Country i |
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All Inventors Must Be Listed – Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. — Add

| | |
|---|---|
| **Title of Invention** | A method and device for personalized pulse oximetry |
| Attorney Docket Number (if applicable) | 376/P1-USP |

## Correspondence Address

Direct all correspondence to (select one):

| | |
|---|---|
| ◉ The address corresponding to Customer Number | ○ Firm or Individual Name |
| Customer Number | 11351 |

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

◉ No.

○ Yes, the name of the U.S. Government agency and the Government contract number are:

Doc Code: **TR.PROV**
Document Description: Provisional Cover Sheet (SB16)

PTO/SB/16 (11-08)
Approved for use through 05/31/2015. OMB 0651-0032
U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE


## Entity Status

Applicant claims small entity status under 37 CFR 1.27

- (●) Yes, applicant qualifies for small entity status under 37 CFR 1.27
- ( ) No

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## Signature

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| | | | | | |
|---|---|---|---|---|---|
| Signature | /M.Sarap/ | | | Date (YYYY-MM-DD) | 2013-03-03 |
| First Name | Margus | Last Name | SARAP | Registration Number (If appropriate) | |

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# Curriculum vitae

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Name: Erve Sõõru
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**Education**

| Educational institution | Graduation year | Education (Field of study/degree) |
|---|---|---|
| Tallinn University of Technology, Department of Health Technologies | exp. 2019 | PhD in Health Technologies |
| University of Tartu, Tartu University Lung Clinic, Residency in Pulmonary Medicine | 2002 | Pulmonologist |
| University of Tartu, Faculty of Medicine, Internship | 1997 | License in General Medicine |
| University of Tartu, Faculty of Medicine | 1993 | MD, Physician in sports medicine and rehabilitation |
| Tallinn Sports Boarding School, Otepää Branch | 1986 | Secondary education, biathlon |

**Language competence**

| Language | Level |
|---|---|
| Estonian | Mother tongue |
| English | Very good |
| Russian | Very good |

**Professional employment**

| Period | Organization | Position |
|---|---|---|
| 2016 to date | Confido Private Medical Centre | Specialist in pulmonary medicine and sleep medicine |
| 2013 to date | Tallinn University of Technology, Department of Health Technologies | Lecturer (0.2) |
| 2002 – 2019 | North Estonia Medical Centre, Department of Pulmonology | Specialist in pulmonary medicine; Senior adviser |
| 1998 – 2002 | Tartu University Lung Clinic, Department of Pulmonology, Residency of Pulmonary Medicine | Assistant physician |
| 2001 – 2003 | Estonian Genome Project | Research investigator |

| | | |
|---|---|---|
| 1993 – 1998 | University of Tartu, Faculty of Medicine | Physician-intern |

**Managerial and administrative work**

| Period | Position |
|---|---|
| 1998 to date | Estonian Respiratory Society, Member |
| 1999 to date | European Respiratory Society, Member |
| 2005 to date | Estonian Sleep Medicine Association, Founder, Member of board, President (2011 – 2018) |
| 2012 to date | European Sleep Research Society, Member |
| 2012 – 2018 | European Sleep Research Society, 22nd Congress, Chair of local organising committee (2014, Tallinn) |
| 2012 – 2018 | European Sleep Research Society, Assembly of National Societies, national representative |
| 2013 to date | Nordic Sleep Society, Member of board |
| 2013 | European Sleep Research Society, accredited as an Expert in Sleep Medicine |
| 2014 – 2017 | Nordic Sleep Conference, Chair of organising committee (2017, Tallinn) |
| 2016 – 2019 | Nordic Lung Conference, Member of scientific and organising committee (2019, Tallinn) |

**Publications**


1. **Sõõru, E.** Täiskasvanute unehäirete esmane diagnostika. (2019). Eesti Arst; 98(7):375–376.
2. Põld, K., **Sõõru, E**., Hion, T., Kiens, O. Eesti Unemeditsiini Selts Põhjamaade unemeditsiinikonverentsil. (2019) Eesti Arst; 98(7):412–413.
3. Hazak, Aaro; **Sõõru, Erve**; Hein, Heili; Männasoo, Kadri (Epub ahead a print). Effects of work arrangements on the sleep regimen of creative R&D employees. International Journal of Occupational Safety and Ergonomics.10.1080/10803548.2018.1504854 .
4. **Sõõru, E.**, Ingerainen, D., Hion, T., Pallo, V., Immato, E. (2019). Estonian eHealth for screening obstructive sleep apnea among drivers. Poster presentation. The 49th Nordic Lung Congress. Endorsed by European Respiratory Society. Tallinn, Estonia, 12–14 June, 2019.
5. **Sõõru, E.**, Hion, T., Põld, K. et al. (2019). Täiskasvanute unehäirete esmane diagnostika. Eesti Haigekassa. Ravijuhend. (RJ-G/28.1-2018).
6. **Sõõru, E**., Hazak, A., Rebane, M. (Epub ahead of print). Does chronotype restrict the employment options of creative R&D professionals? Biological Rhythm Research.
7. **Sõõru, E.**, Hazak, A., Männasoo, K. (2018). Effects of work arrangement on sleep regimen in creative R&D employees. Journal of Sleep Research, 27: 24th Congress of the European-Sleep-Research-Society (ESRS). Basel, Switzerland: Wiley, 208‒208. (S1).10.1111/jsr.12751.

8. **Sõõru, E.**, Hazak, A., Partinen, M., Virkebau, M. (2018). Daytime sleepiness: impacts of work organisation. Journal of Sleep Research, 27: 24th Congress of the European-Sleep-Research-Society (ESRS). Basel, Switzerland: Wiley, 208−208. (S1).10.1111/jsr.12751.
9. **Sõõru, E.**, Hein, H., Hazak, A. (2017). Why force owls to start work early? The work schedules of R&D employees and sleep. In: TUT Economic Research Series. (TUTECON Research Briefs; No. RB-2017/3).
10. Arnardottir, E. S., Verbraecken, J., Gonçalves, M., Gjerstad, M. D., Grote, L., Puertas, F. J., Mihaicuta, S., McNicholas, W. T., Parrino, L.; National Representatives as Study Collaborators. (**Sõõru, E.** et al.). (2016). Variability in recording and scoring of respiratory events during sleep in Europe: a need for uniform standards. J Sleep Res. 2016 Apr; 25(2):144–157. doi: 10.1111/jsr.12353.
11. Hazak, A., Virkebau, M., Tuulik, V., Tint, P., Pille, V., **Sõõru, E.** (2016). Social innovation potential in working arrangements of R&D employees: Repeated employee survey from Estonia. In: 2016 IEEE International Conference on Emerging Technologies and Innovative Business Practices for the Transformation of Societies (EmergiTech) (210−213). IEEE.10.1109/EmergiTech.2016.7737340.
12. Hazak, A., Virkebau, M., Tuulik, V., Tint, P., Pille, V., **Sõõru, E.** (2016). Employee Performance, Working Time and Tiredness in Creative R&D Jobs: Employee Survey from Estonia. The Economies of Balkan and Eastern Europe Countries in the Changed World. Book of Abstracts: 8th International Conference EBEEC. Split, Croatia: Eastern Macedonia and Thrace Institute of Technology, 77.
13. Hazak, A., Virkebau, M., **Sõõru, E.**, Männasoo, K., Tuulik, V. (2016). Effects of working time patterns on creative R&D work outcome. Hard Times?: The Eighth Nordic Working Life Conference, Tampere, 2–4 November 2016. University of Tampere, 49−49.
14. **Sõõru, E.**, Ross, P., Sepper, R. (2015). E-health and screening possibilities of obstructive sleep apnea among drivers. 16th Nordic Sleep Conference jointly organized with the 8th Annual Congress of the Swedish Sleep Society. Gothenburg, Sweden, 21–23 May, 2015.
15. Gonçalves, M., Amici, R., Lucas, R., Åkerstedt, T., Cirignotta, F., Horne, J., Léger, D., McNicholas, W. T., Partinen, M., Téran-Santos, J., Peigneux, P., Grote, L.; National Representatives as Study Collaborators (**Sõõru, E.** et al.).(2015). Sleepiness at the wheel across Europe: a survey of 19 countries. J Sleep Res. Jun; 24(3):242–253.
16. **Sõõru, E.**, Innos, K., Sepper, R. (2015). The effect of age, BMI and different diseases on the oxygen desaturation index among men and women. 16th Nordic Sleep Conference jointly organized with the 8th Annual Congress of the Swedish Sleep Society. Gothenburg, Sweden, 21–23 May, 2015.
17. **Sõõru, E.** (2014). Management of obstructive sleep apnoea among drivers in Estonia. European Sleep Research Society 22nd Congress, Tallinn, Estonia, 16–20 September, 2014.
18. **Sõõru, E.**, Innos, K., Sepper, R. (2014). The effect of age, gender, BMI and hypertension on the oxygen desaturation index. European Sleep Research Society 22nd Congress, Tallinn, Estonia, 16–20 September, 2014.

19. **Sõõru, E.**, Kõre, K., Nagelmann, A. (2011). Effects of the Home-Realized 6 Months Follow-up Study Individually Designed Exercise Programme in Patients with Severe Chronic Obstructive Pulmonary Disease. CHEST: The annual meeting of the American College of Chest Physicians, Honolulu, Oct. 22 to 26 2011. American College of Chest Physicians. (Chest; 140 (4 Meeting Abstracts)).10.1378/chest.1117548.
20. **Sõõru, E.** (2007). Mitteinvasiivne ventilatsioon - meie võimalused uneaegsete hingamishäirete ravimisel. Eesti Arst, Lisa 10: III Eesti Unemeditsiini Konverents "Mida parem uni, seda turvalisem elu". Eesti Rahvusraamatukogu, 13 Aprill, 2007.
21. **Sõõru, E.**, Kõre, K., Nagelmann, A. (2006). Effects of the home-realized 6 months follow-up study individually designed exercise programme on patients with severe chronic obstructive pulmonary disease. ERS Annual Congress 2006 - ABSTRACTS. 553s.
22. **Sõõru, E.**, Jõgi, R., Jaanus, M. (2004). Obstruktiivne uneapnoe: diagnostika ja ravi. Ravijuhend. Tartu: Tartu Ülikool.
23. Tuvik, P., **Sõõru, E.** (2003). ANCA-positiivsed vaskuliidid - kolm haigusjuhtu kopsuarsti vaatevinklist. Eesti Arst, 5, 254.
24. **Sõõru, E.**, Jõgi, R. (2002). Overview of the current situation in diagnosing and treating obstructive sleep apnoea in Estonia. Medicina Thoracalis: Soome-Ugri Kopsuarstide Kongress, Pecs, Ungari, 23–25 May 2002. 46−47.
25. **Sõõru, E.**, Altraja, A. (2001). Obstruktiivse uneapnoe sündroom ja selle CPAP-ravi kui ravi valikmeetod. Eesti Arst, 80(8):341−346.

**Invention**

A method and device for personalized pulse oximetry; Owners: RES-MEDICA OÜ, ELIKO Tehnoloogia Arenduskeskus OÜ; Authors: **Erve Sõõru**, Mart Min, Paul Annus, Raul Land; Priority number: US 61/771,903; Priority date: 03.03.2013.

# Elulookirjeldus

**Isikuandmed**

| | |
|---|---|
| Nimi: | Erve Sõõru |
| Sünniaeg ja -koht: | 18.12.1968, Tartu, Eesti |
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**Kontaktandmed**

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**Hariduskäik**

| Õppeasutus | Lõpetamise aeg | Haridus (Eriala/kraad) |
|---|---|---|
| Tallinna Tehnikaülikool, Tervisetehnoloogia Instituut, Doktorantuur | Oodatav 2019 | Tervisetehnoloogia- PhD |
| Tartu Ülikool, Tartu Ülikooli Kopsukliinik, Residentuur | 2002 | Kopsuarsti kutse |
| Tartu Ülikool, Arstiteaduskond, Internatuur | 1997 | Üldarsti kutse |
| Tartu Ülikool, Arstiteaduskond | 1993 | Meditsiinidoktor, ravi eriala; spordimeditsiini ja taastusravi arsti kutse |
| Tallinna Spordiinternaatkool (TSIK), Otepää filiaal | 1986 | keskharidus, laskesuusatamine |

**Keelteoskus**

| Keel | Tase |
|---|---|
| Eesti | Emakeel, kõrgtase |
| Inglise | Kõrgtase |
| Vene | Kõrgtase |

**Teenistuskäik**

| Töötamise aeg | Tööandja nimetus | Ametikoht |
|---|---|---|
| 2016 – | Confido Erameditsiinikeskus | Kopsuarst - unearst |
| 2013 – | Tallinna Tehnikaülikool, Tervisetehnoloogia instituut | Lektor (0,2) |
| 2002 – 2019 | Põhja-Eesti Regionaalhaigla, Pulmonoloogia osakond | Kopsuarst-vanemarst |
| 1998 – 2002 | Tartu Ülikool, Arstiteaduskond, Residentuur pulmonoloogia erialal | Arst- resident |
| 2001 – 2003 | Eesti Geenivaramu | Uuringute monitoorija |
| 1993 – 1997 | Tartu Ülikool, Arstiteaduskond, Internatuur | Arst-intern |

**Teadusorganisatsiooniline ja administratiivne tegevus**

| **Periood** | **Tegevus** |
|---|---|
| 1998 – | Eesti Kopsuarstide Seltsi liige |
| 1999 – | Euroopa Kopsuarstide Seltsi liige |
| 2005 – | Eesti Unemeditsiini Seltsi asutaja, juhatuse liige, president (2011 – 2018) |
| 2012 – | Euroopa Unemeditsiini Seltsi liige |
| 2012 – 2018 | Euroopa Unemeditsiini Seltsi kongressi korralduskomitee juht (2014, Tallinn) |
| 2012 – 2018 | Euroopa Uneuurijate Seltside Kogu, rahvuslik esindaja |
| 2013 – | Põhjamaade Unemeditsiini Selts, juhatuse liige |
| 2013 | Euroopa Uneuurijate Seltsi poolt akrediteeritud unemeditsiini ekspert |
| 2014 – 2017 | Põhjamaade Unemeditsiini Kongressi korralduskomitee juht (2017, Tallinn) |
| 2016 – 2019 | Põhjamaade Kopsuarstide Kongressi korralduskomitee ja teaduskomitee liige (2019, Tallinn) |