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PREPARATION AND PROCESSING OF A LARGE-SCALE HEART RATE VARIABILITY AND LIFESTYLE ASSESSMENT DATA

Master Of Science Thesis

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Tässä työssä kootaan tietokanta Hyvinvointianalyysi-tuloksista, joita Firstbeat Technologies Oy on tehnyt noin 20 000 suomalaiselle vuosina 2000–2013. Hyvinvointianalyysissä sydämen sykevälivaihtelua mitataan kolmen päivän ajan, minkä perusteella arvioidaan kehon fysiologista tilaa. Sydämen sykevälivaihtelu pienenee stressireaktioiden aikana ja kasvaa palautumisen aikana. Myös fyysinen aktiivisuus aiheuttaa muutoksia sykkeessä ja sykevälivaihtelussa. Hyvinvointianalyysin tulokset ovat siis arvioita kehon fysiologisista tiloista, kuten stressistä, palautumisesta ja fyysisestä aktiivisuudesta, sekä niiden määristä.

Tietokanta sisältää taustatietoja mitatuista henkilöistä, esimerkiksi sukupuoli, ikä ja fyysisen aktiivisuuden tasoa kuvaava aktiivisuusluokka, mittauspäivien tapahtumista, esimerkiksi työaika, sekä Hyvinvointianalyysien tulokset, jotka on tietokannassa esitetty valittuina ajallisina muuttujina, joiden tyypillisin resoluutio on 10 minuuttia. Ajalliset muuttujat on esitetty mittauspäivittäin, jotka kuvaavat henkilön luonnollista vuorokausirytmiä. Ajallisten muuttujien ansiosta tietokannan tuloksia voidaan tarkastella erikseen esimerkiksi unen tai työn ajoilta ja ne mahdollistavat eri fysiologisten tilojen vuorokausirytmin arvioinnin. Tietokannan tulosten yksinkertaisiin analyyseihin voidaan käyttää osana tätä työtä toteutettua graafista käyttöliittymää.

Muodostetun tietokannan sisältämiä tuloksia tarkastellaan tässä työssä tilastollisesti sukupuolten, aktiivisuusluokkaryhmien, ikäryhmien ja painoindeksiryhmien välillä. Myös työ- ja vapaapäivien välillä tarkastellaan joitakin tuloksia. Tilastollisesti merkitsevien tulosten mukaan iän myötä unen laatu heikkenee ja stressi sekä energian kulutus pienenevät. Molemmilla sukupuolilla korkea aktiivisuusluokka ja matala painoindeksi ovat yhteydessä hyvään uneen laatuun, alhaiseen stressiin ja suureen energian kulutukseen. Lisäksi miehillä korkea aktiivisuusluokka ja matala painoindeksi lisäävät sykevälivaihtelua. Miehillä on enemmän stressiä, parempi unen laatu, enemmän fyysistä aktiivisuutta ja suurempi energian kulutus kuin naisilla. Fyysisen aktiivisuuden määrän havaittiin olevan suurempi työ- kuin vapaapäivinä sekä miehillä että naisilla.

Tämän tietokannan vahvuuksia ovat sen suuri koko ja sen sisältämä monimuotoinen tieto henkilöiden fysiologisista tiloista ja parametrien arvoista. Tulevaisuudessa tämän tietokannan avulla voidaankin tutkia monenlaisia tutkimuskysymyksiä.

ABSTRACT

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In this thesis, a database is constructed from Lifestyle Assessment results conducted by Firstbeat Technologies Ltd in years 2000–2013 for about 20 000 Finns. The Lifestyle Assessment is a three-day heart rate variability (HRV) measurement which is used for estimating the physiological state of the body. HRV decreases during stress and HRV increases during recovery. Moreover, physical activity affects heart rate and HRV. Thus, the Lifestyle Assessment Results are estimates about the physiological states of the body, such as stress, recovery and physical activity, and their amounts.

The database includes background parameters, for example subject's gender, age and level of physical activity assessed by activity class (AC), the events of measurement days, for example the working hours, and the Lifestyle Assessment Results presented as selected time dependent variables whose typical resolution is 10 minutes. The time dependent variables are presented by measurement days describing the circadian rhythm of the subject. The time dependent variables enable assessing the results separately for work or sleep, for instance. Moreover, the circadian rhythm of the physiological states can be assessed with this database's results. The graphical user interface, implemented as a part of this thesis work, can be used for simple analysis of the database's results.

In this thesis, the results of the database are analyzed using statistical methods. The results are studied between the genders, the age groups, the body-mass-index (BMI) groups and the AC groups. Some results are studied also between working days and days off. The statistically significant results show that HRV, quality of sleep and the amounts of stress and energy expenditure decrease with age. In both genders the high AC and low BMI are related to good quality of sleep, low amount of stress and high EE. In men the high AC and low BMI are also related to increase in HRV. In men the amount of stress is greater than in women but the quality of sleep is better in men than in women. Moreover, men have greater energy expenditure and more health promoting physical activity than women. The physical activity was found out to be greater during work days than days off in both men and women.

The advantages of this database are its big size and the variety of information the database includes about the subjects' physiological states and parameters. In future, variety of research questions can be studied using this database.

PREFACE

This thesis work was carried out between April 2013 and May 2014 in the Department of Signal Processing at Tampere University of Technology in close collaboration with Firstbeat Technologies Ltd.

I would like to thank my supervisor D.Sc. Elina Helander for her guidance and support during the thesis work. I would also like to thank Professor Ilkka Korhonen and Professor Jari Hyttinen for their advice, comments and suggestions to improve my thesis.

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Tampere, May 2014

Julia Pietilä

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ABBREVIATIONS

AC	self-reported activity class
ACSM	American College of Sports Medicine
ANS	the autonomic nervous system
BMI	body mass index
CO	cardiac output
CVD	cardio vascular disease
ECG	electrocardiogram
EE	energy expenditure
GUI	graphical user interface
HF	high frequency component of the HRV
HR	heart rate
HR_{max}	maximum heart rate
HRV	heart rate variability
LF	low frequency component of the HRV
LF/HF	the ratio of low frequency power and high frequency power
MET	metabolic equivalent
NN interval	normal-to-normal interval
PNS	the parasympathetic nervous system
RMSSD	the square root mean of the successive beat-to-beat time intervals
RR interval	time between two consecutive R-peaks in the ECG
SA node	sino-atrial node
SD	standard deviation
SNS	the sympathetic nervous system
VLF	very low frequency component of HRV
VO_2	oxygen consumption
VO_{2max}	maximal oxygen consumption

1 INTRODUCTION

In general, health is one of the most important components of good life (Nieminen-Sundell 2011, p. 16). Nowadays people are also more conscious about the impact of their lifestyles on their health and well-being as the researchers have shown there is a link between lifestyles, well-being and diseases. Cancer, coronary artery disease and type 2 diabetes are examples of diseases which are related to lifestyles (Key et al. 2002; Astrup 2001; McCullough 2007). The healthy lifestyles, including non-smoking, physical activity, healthy eating habits and reasonable alcohol consumption, decrease a risk of having a lifestyle disease, whereas the non-healthy lifestyles increase the risk. Consequently, obeying healthy lifestyles is supposed to increase the healthy years of life.

Even though the understanding about the contribution of lifestyles to diseases has increased over the years, still some of lifestyle related diseases are becoming more common. The lifestyle related diseases cause both indirect and direct costs and the total costs increase with the number of people having a disease. For example, in Finland the number of people having a type 2 diabetes is estimated to double in every twelve years (Winell & Reunanen 2006, p. 13) and simultaneously, the costs of diabetes are continuously increasing (Jarvala et al. 2010). Consequently, the Finnish health policy aims at preventing diseases and promoting health. The Finnish health policy is based on the Health For All program of World Health Organization. (Terveys 2015 – kansanterveysohjelma.)

In addition to the public sector, the Finnish health policy also applies to the occupational health care services. In other words, the occupational health care services are supposed to offer health promoting services for the companies' employees. As a result, there is a demand for companies providing welfare and well-being services. One of these companies is Firstbeat Technologies Ltd.

Firstbeat Technologies Ltd has developed Lifestyle Assessment which is used in occupational health care services to analyze the well-being of employees. The Firstbeat measurement procedure is based on a heart rate variability (HRV) measurement which implicates many of the aspects of well-being, such as stress, recovery and physical activity. The measurement is performed in real-life conditions typically for three days. Firstbeat Technologies Ltd has been providing the measurements from 2002 onwards and as a by-product of Firstbeat's business a database considering the well-being of about 20 000 Finns has been formed. There are some HRV databases but the database which is constructed from the Firstbeat measurements is unique because it includes a great number of measurements which are performed in real-life conditions. Moreover, in addition to the HRV parameters, the Firstbeat measurements include estimations about the physiological states of the subject during the measurement. The database of Firstbeat measurements also enables comparing objective measurement results, such as the amount of physical activity, with subjective measurement results, for example.the pre questionnaire results about physical activity.

The purpose of this thesis is to describe how the Firstbeat measurements are processed into a uniform database and to find out how the Firstbeat measurement results are connected to the background parameters of the subject. Chapter 2 considers the relations of physiology and HRV as well as measuring HRV. In Chapter 3, the thesis introduces the Firstbeat measurement procedure itself and the methods, developed by Firstbeat Technologies Ltd, used for estimating the physiology of the subject based on the HRV measurement. Chapter 3 also introduces all the information available from the Firstbeat measurements and the preprocessing of the measurement results. The processing of the preprocessed Firstbeat measurements into a database is described in Chapter 4. Moreover, the graphical user interface which was implemented as a part of this work as a tool for simple analysis of the database is introduced. The database enables the systematic analysis of the Firstbeat measurements and the database's results about physical activity, stress, recovery, HRV parameters and circadian rhythm of the physiological states among the working-age Finnish subjects are introduced in Chapter 5. Chapter 6 concludes the thesis.

2 HEART RATE VARIABILITY AND PHYSIOLOGY

Heart rate variability (HRV) is a measure which enables assessing the physiological states of the body, such as stress and recovery as well as physical activity, from a measured heart rate (HR) signal. The physiological states can be assessed based on HRV measurement as HRV is in relation to autonomic nervous system. In other words, HRV reflects the balance between sympathetic and parasympathetic branches of the autonomic nervous system.

2.1 Heart rate variability measurement

HRV is typically measured non-invasively from the skin by electrodes. For example, the basic electrocardiograph can be used for assessing HRV. The HRV is a consequence of several physiological reflexes and their interactions which are maintaining the cardiovascular balance. However, also other factors have their impact on HRV. There are several different variables which are used to describe HRV.

2.1.1 HRV and its physiological background

The cardiac cycle starts from spontaneously depolarizing pacemaker cells which locate in the sino-atrial (SA) node of the heart. From the pacemaker cells the depolarization spreads through special pathways over the atria and ventricles. In electrocardiogram (ECG) the depolarization of atria is shown as a P wave and during the QRS complex the ventricles are depolarized (Figure 2.1). The depolarization of the cells makes heart muscle to contract and pump blood. After pumping blood into the arteries, the ventricles repolarize and relax, shown as a T wave in the ECG (Figure 2.1), and the heart fills with blood before a new cardiac cycle starts. The duration of a cardiac cycle is usually measured with RR interval (Figure 2.1) as the R peaks can easily be detected from the ECG. (Acharya et al. 2007, p. 121.)

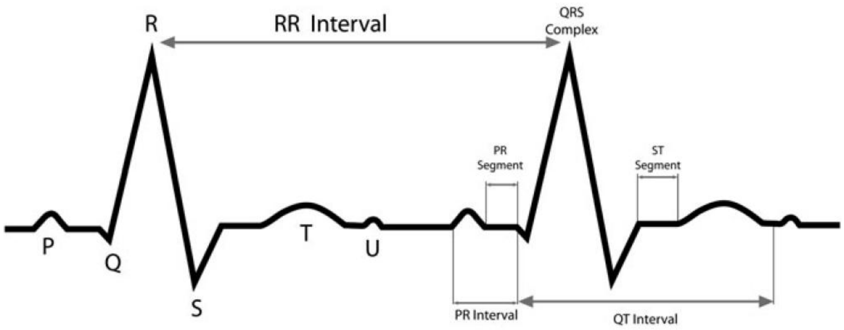


Figure 2.1. *An ideal figure of ECG representing two heart cycles* (Wasilewski & Polonski 2012, p. 7).

Intrinsically, the pacemaker cells depolarize about 100–120 times per minute (Acharya et al. 2007, p. 121). However, in order to maintain cardiovascular balance, the depolarization rate of the pacemaker cells is controlled by the autonomic nervous system (ANS) (Freeman & Bonyhay 2003, p. 317). The ANS affects the heart by its two separate branches which are the sympathetic nervous system (SNS) and the parasympathetic nervous systems (PNS). These two branches have opposite effects on the heart: the SNS stimulates the functions of the heart, whereas the PNS inhibits the functions of the heart. Considering HR, the activation of the SNS, which is dominant during stress and exercise, results in increased HR, whereas the activation of PNS, which is dominant at rest, decreases HR. (Acharya et al. 2007, pp. 122,124.) Consequently, the ANS and its two branches enable the cardiovascular system to adjust to the changing demands of the body (Andresen & Mendelowitz 2009, p. 863).

One of the most important reflexes in maintaining the cardiovascular balance and regulating the balance between the SNS and the PNS is arterial baroreflex. The arterial baroreflex is based on baroreceptors, located in the heart and in the centralmost arteries and vessels, which are continuously sensing the arterial pressure and its changes. The baroreceptor stimulation is transmitted to both the SNS and the PNS, which enables rapid adjustments for the cardiovascular balance. (Andresen & Mendelowitz 2009, p. 863.)

Also the respiration is coupled with the cardiovascular balance as it affects HR and blood pressure (BP). In normal subjects, during inspiration HR increases and BP decreases and during expiration HR decreases and BP increases. The respiration is affecting the cardiovascular balance by several ways. The respiration directly affects the activity of the SNS and the PNS (Saul et al 1991, cited in Korhonen 1997, p. 20). On the other hand, during respiration cycle the intrathoracic pressure changes, which in turn results in changing BP, and thus, the baroreceptor stimulation (Saul et al 1991, Toska 1995, cited in Korhonen 1997, p. 20). Moreover, the respiration motion itself may stretch baroreceptors (Schmidt & Thews 1983, Toska 1995, cited in Korhonen 1997 p. 20).

The continuous maintaining of the cardiovascular balance results in, among others, varying HR and varying RR intervals. The variation in HR or in RR intervals is measured by a parameter called HRV. (Sztajzel 2004, p. 516.) The HRV can be assessed from the ECG signal. Firstly, the QRS complexes i.e. usually the R peaks are detected, and thereafter, the durations of RR intervals are calculated (Figure 2.1). The time series of the RR intervals is the HRV signal. An example of HRV signal is shown in Figure 2.2.

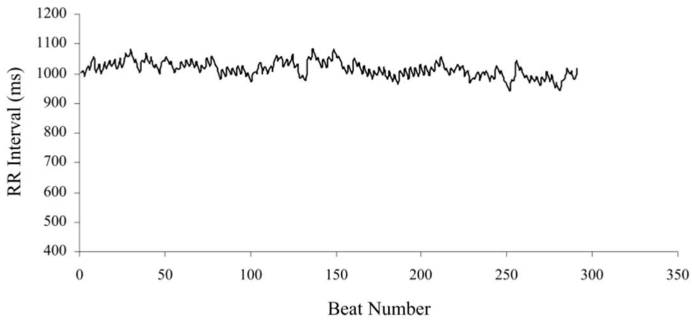


Figure 2.2. *An example of HRV signal (*Singh et al 2004*).*

Because the ANS is responsible for regulating the heart functions, HRV is considered to assess the state of the ANS (Acharya et al. 2007, p. 122). Diminished HRV is interpreted to be a consequence of increased sympathetic activity or decreased vagal activity (Task Force 1996, p. 366). The PNS can regulate the heart functions rapidly, whereas the SNS regulates the heart functions slower (Pumprla et al 2002, p. 2). The respiratory component is vagally mediated and therefore, respiration has acute and relatively short-term effect on HRV (Andresen & Mendelowitz 2009, p. 863.). As the respiration frequency decreases, HRV increases. (Patterson & Kaiser 1997, cited in Acharya et al. 2007, p. 127).

2.1.2 Factors affecting HRV

HRV is regarded to reflect the heart's ability to adapt to changes, and that is why HRV is considered as a measure of overall cardiac health (Acharya et al. 2007, p. 122). Subjects with myocardial infarction have lowered HRV when compared to the controls (Rothschild et al. 1988, cited in Acharya et al. 2007, p. 125).

In addition to cardiac health, HRV has been found out to be in association with other physiological as well as psychological diseases. Renal failure and diabetes are examples of physiological diseases reducing HRV (Axelrod et al. 1987; Kudat et al. 2006). In fact, Pfeifer et al. (1982) suggested that in diabetic patients vagal activity is reduced already before clinical symptoms. A psychological disease which might have an effect on HRV is depression. Carney et al. (2001) found out that the patients having a post myocardial infarction and depression had decreased HRV when compare to patients having only a post myocardial infarction. However, Sayar et al. (2002) did not observe statistically significant difference between physically healthy depressed adults and the controls in their study. Consequently, the effect of depression on HRV is still in doubt.

HRV differs also according to gender, age and lifestyle. Young men have increased HRV when compared to young women. However, in both men and women, the overall HRV level continuously decreases with age. The decrease in HRV with age considers especially HRV at nighttime. (Bonnemeier et al. 2003, p. 795.) Smokers have reduced HRV when compared to the controls (Acharya et al. 2007, p. 129).

Moreover, there are several factors which have a short-term effect on HRV. Fatigue is related to increased parasympathetic activity (Acharya et al. 2007, p. 131). Intake of alcohol decreases HRV acutely (Acharya et al. 2007, p. 130). Also some drugs affect HRV and thus, HRV may not be an applicable indicator of cardiac health in patients using, for example, beta-blockers (Acharya et al. 2007, p. 129). Moreover, circadian rhythm is seen in HRV. HRV increases during sleep and it decreases during waking hours (Bonnemeier et al. 2003).

2.1.3 HRV and artefacts

The artefacts in HRV signal are either extrinsic or intrinsic. The extrinsic artefacts are caused by the magnetic or electric fields in the measurement environment, which interact with the measurement device and disturb the measurement signal (Saalasti 2003, p. 28). On the other hand, the physiological aspects may also cause artefacts to the HRV signal because they cause failures in the R peak detection. Arrhythmias, such as tachycardia or bradycardia, are physiological conditions which may cause failures in the detection of R peaks (Mulder 2008, cited in Saalasti 2003, p. 28). In addition to arrhythmias, baseline wander due to respiration motion, great T wave compared to R wave and noise caused by, for instance, bodily movements or loose electrode contact may as well result in failures in the R peak detection (Porges et al. 1992, cited in Saalasti 2003, p. 28).

In order to reduce the artefacts in the HRV measurement, some technical requirements and recommendations have been given. The sampling frequency of the measurement device should be at least 250 Hz and the R peak detection algorithm should be robust. (Task Force 1996, p. 359–360)

2.1.4 HRV parameters

HRV can be described by both time and frequency domain analysis measures. The durations of the recordings, from which HRV measures values are calculated, are recommended to be 5 minutes for short-term recordings and 24 hours for long-term recordings (Task Force, p. 355).

The square root of the mean squared differences of normal-to-normal intervals (RMSSD) is a time domain measure of HRV estimating the HRV from the differences in consecutive RR intervals. The RR intervals should be so called normal-to-normal intervals in which the heartbeats are generated by the depolarization of the pacemaker cells in the SA node. RMMSD is a time domain analysis measure of HRV which estimates the short-term changes of HRV. (Task Force 1996, p. 355, 357) RMSSD is calculated as a square root mean of successive RR intervals:

$$RMSSD = \sqrt{\frac{1}{N-1}\left(\sum_{i=1}^{N-1}(RR_{i+1} - RR_i)^2\right)} \qquad \text{(Eq. 2.1)}$$

where N is the number of RR intervals in time segment (Ribeiro et al. 2001, p. 873). Because RMSSD is dependent on N i.e. the duration of the time segment, the time segment must be standardized in order to compare the RMSSD values of different measurements. A recommended time segment is 5 minutes. (Task Force 1996, p. 355.) The unit of RMSSD is the same as the unit of the RR interval i.e. millisecond (ms) and RMSSD reflects alterations in HR which are mainly induced by the PNS (Sztajzel 2004, p. 516–517).

The frequency domain analysis measures describe the power spectral density of the components. The idea of frequency domain analysis is to find out the power of different frequency bands in the ECG. The most often used frequency bands, into which the ECG is divided, are frequencies lower than 0.04 Hz, denoted as VLF, frequencies of 0.04–0.15 Hz, denoted as LF, and frequencies of 0.15–0.40 Hz, denoted as HF. For each frequency band power spectral density is calculated. The unit is squared milliseconds (ms^2). LF/HF ratio is calculated by dividing low frequency power by the high frequency power and thus, it does not have a unit. (Sztajzel 2004, p. 517.)

The frequency domain variables represent primarily the fluctuations in the balance of the ANS, and the frequency domain variables interpretations consider the activity of the SNS and the PNS. VLF is suggested to reflect the sympathetic activity (Sztajzel 2004, p. 518), whereas HF is agreed to reflect the vagal activity (Task Force 1996, p. 366). The interpretation of LF is not that simple, since it reflects modulations of both the SNS and the PNS. However, in practice, the increase in LF is usually regarded to result from activity of the SNS. LF/HF ratio represents the overall sympatho-vagal balance of the ANS. (Sztajzel 2004, p. 518.) The LF/HF ratio is not easily related to activity of the SNS or the PNS since an increased LF/HF ratio may reflect increased activity of the SNS, decreased activity of the PNS or both of them (Terathongkum & Pickler 2004). Nevertheless, the increased LF/HF ratio reflects decreased HRV since both increase in the SNS and decrease in the PNS decrease HRV.

2.2 Stress

In everyday language the word stress is usually related to negative feelings. However, the stress response is vital since without it surviving from daily events is impossible.

The stress response is harmful for the body only if the normal stress response is disturbed or prolonged. (McEwen 2007, p. 874.) The chronic stress causes changes to the cardiovascular and immune systems, for instance (McEwen 2007, p. 879; McEwen 1998, p. 41).

A physiological stress is body’s respond to a stressor. Stressors are divided into psychosocial and biogenic stressors. Biogenic stressors, such as caffeine and nicotine, can cause a stress response directly because of their biochemical properties. On contrary, the psychosocial stimulus, for example worries, interpersonal conflicts or environmental events, cannot directly cause a stress reaction in the body. The psychological stimulus is always considered cognitively and affectively before it becomes a psychosocial stressor. (Everly et al. 2013, p. 27.) In other words, the stressfulness of the situation is determined by the individual and their life experiences. Accordingly, brain is the organ controlling the stress response to psychosocial stressor. (McEwen 2007, p. 874, 877.) As a result, the biogenic stressor starts the stress response in the body immediately but the responses to possible psychological stressors vary individually.

The physiological stress response is the same whether it is caused by a biogenic or psychosocial stressor. The stress response activates the systems of the body, such as the autonomic nervous system, the hypothalamo-pituitary-adrenal axis, the immune system and the central nervous system, which are responsible for promoting the body’s adaption to the stressors (McEwen 1998, p. 33). These systems cause typical indicators of stress, such as increased heart rate and blood pressure (McEwen 2007, p. 879).

Many studies indicate that the physiological stress response is also in association with reduced HRV. In some of the studies the relation of decreased HRV and stress is associated with activation of the sympathetic branch of the ANS during stress. In other studies, the reduction in vagal activity during stress is considered as a reason for reduced HRV during stress. However, there are also studies in which no relation between reduced HRV and stress has been found out. Consequently, there is no consensus among researchers about the association of stress and HRV. (Lindholm 2013, p. 35–37.)

The physiological stress response should be rapidly turned on after exposure to the stressor and rapidly turned off as the stressor no longer exists (McEwen 2007, p. 880). The body’s ability rapidly to adapt to the changing circumstances, such as the state of the body, the external environment, aversive stimulus and threats is called as allostasis (McEwen 1998, p. 37). The normal stress response i.e. allostasis enables the body to maintain its balance in spite of the changing circumstances (McEwen 2007, p. 880).

However, in some cases the stress response continues even the stressor has vanished and the stress response becomes damaging for the body. The state of the body in which the stress has become chronic and the allostasis is disturbed is referred as allostatic overload. In the allostatic overload the stress response is either prolonged, the adaption to stress response is decreased or the stress response is inadequate (McEwen 2007, p. 880). The allostatic overload is induced by an excessive amount of stress, frequent stress or a lack of recovery (McEwen 1998, p. 39–40).

The prolonged stress response results in, among others, chronically increased heart rate and blood pressure, which over time causes changes in the cardiovascular system (McEwen 2007, p. 879). In addition to the changes in the cardiovascular system, chronic stress is also suggested to cause an increased risk to inflammatory and autoimmune diseases (McEwen 1998, p. 41). Even a risk for developing cancer may be increased as a result of chronic stress (McEwen 1998, p. 37).

2.3 Recovery

Recovery is defined as “unwinding after exposure to demands and stressors” (Lindholm 2013, p. 22). In other words, recovery normalizes the body reactions after a stress response and thus, the stress level of the body does not become too high nor does the stress reaction take for too long. Recovery reactions are opposite to the reactions of the body in stress (McEwen 2007, p. 881) and thus recovery reactions decrease BP and HR. Furthermore, during recovery the PNS is predominant (Vrijkotte et al. 2000, p. 880) which increases HRV. Consequently, adequate recovery is extremely important in order to avoid prolonged stress and its adverse health consequences (Geurts & Sonnentag 2006, cited in Lindholm 2013, p. 22). The body may recover both during waking hours and sleep but sleep is one of the most important parts of daily recovery. (Lindholm 2013, p. 22).

The Effort-Recovery model, introduced by Meijman & Mulder (1998), is a model which describes the relations of effort and recovery, especially in the means of work. The model is based on an assumption that people try to meet the demands they confront in work.

In the Effort-Recovery model, the effort is defined as a response to work demands, such as work assignments and work facilities and environment, which people daily encounter at work. However, the effort which people put into the task is not constant from day to day but it is dependent both on the demands and on the individual. The demand related issues affecting the effort comprise the features of demands as well as the person’s ability to influence their working and demands. The person’s competence, willingness to qualify and the current psychophysiological state are personal issues defining the effort. Thus, the effort put into the task is formed based on these different aspects. The effort induces two outputs. One of the outputs is a product which is a tangible result of the effort, whereas the other is composed of the short-term physiological reaction of the body and psychophysiological reactions. (Meijman & Mulder 1998.)

As the effort is performed and the person is no longer exposed to the load, the recovery phase begins. During recovery, the psychological and physiological states return to normal. In other words, the recovery normalizes the situation and thus, the body is capable of confronting new demands and coping with them. However, the recovery may be insufficient if the load is prolonged or if the load is short-term but extremely high. (Meijman & Mulder 1998.) In other words, the insufficient recovery may cause allostatic overload of the body which may have severe health consequences (McEwen 1998, p. 39–40).

2.4 Physical activity

Physical activity is a physiological state of the body in which the body consumes energy as a consequence of bodily movement produced by skeletal muscles. Thus, the amount of physical activity can be estimated by the total energy expenditure (EE). (Caspersen et al. 1985, p. 126–127.) In addition to the amount of physical activity, physical activity can be assessed by its intensity. Physical activity should be intensive enough and the total amount of physical activity should be high enough to improve cardiorespiratory fitness. (Garber et al. 2011, p. 1336, 1338.) The cardiorespiratory fitness is defined as the ability of circulatory and respiratory systems to supply oxygen during sustained physical activity (Christensen et al. 2004, p. 104).

The EE can be estimated from HR. The relation between EE and HR is based on the body’s increased oxygen consumption during physical activity since the body responds to the increased need of oxygen by increasing the cardiac output (CO). The increased CO is achieved by increased stroke volume and HR. In moderate to high intensity levels of physical activity, an increase in CO is primarily reached by increasing HR. (Åstrand & Rodahl 1986, cited in Pulkkinen 2003, p. 16.) Consequently, the relation between EE and HR is linear in moderate to high activity levels and non-linear in low and very high intensity levels (Hiilloskorpi et al. 2003, cited in Linnala 2010, p. 18).

The intensity level of physical activity can be assessed by metabolic equivalents (METs) (Garber et al. 2011, p. 1341). MET is defined as the ratio of current EE to EE at rest which is approximated to be 1 J/kg/min on average and which corresponds to the oxygen consumption of 3.5 ml/kg/min. In other words, MET value is a multiple of the EE at rest. (Byrne et al. 2005, p. 1112.) Consequently, the greater the current MET value is, the greater is the current EE and thus, the more intense the physical activity is (Garber et al. 2011, p. 1341).

Because the MET value is a quotient of the current EE and the EE at rest, the MET value of physical activity can be assessed by HR. Firstly, the current EE is estimated from HR by exploiting the above-mentioned relationship between EE and HR. Thereafter, the current EE is compared to the approximated EE at rest, which gives the current MET value.

Physical activity can be categorized according to its intensity i.e. MET values. The intensity of physical activity is relative to the background parameters of the subjects, such as age, fitness level and body-mass-index (BMI). For instance, in order to achieve the moderate intensity of physical activity the young must have a greater MET value than the old. Consequently, the MET values of different intensity levels shown in Table 2.1 are only approximations. (Garber et al. 2011, p. 1341.)

Table 2.1. *Different intensity levels of physical activity and their corresponding MET values* (Garber et al. 2011, p. 1341).

Intensity	*MET values*
Very light	< 2
Light	[2,3)
Moderate	[3,6)
Vigorous	[6,8.8)
Near-maximal to maximal	≥ 8.8

In order to improve health and cardiorespiratory fitness, the amount and the intensity of physical activity must be adequate. The amount of cardiorespiratory physical activity can be estimated by MET-minutes i.e. a product of MET values during physical activity and the duration of physical activity in minutes. Based on the results of various studies, ACSM recommends that in order to improve health and cardiorespiratory fitness, the intensity of the exercise should be at least moderate and/or vigorous (see Table 2.1). A combination of moderate and vigorous exercise is recommended to be performed from three to five times a week in sessions of at least 10 minutes. Overall, the target amount of cardiorespiratory exercise is at least 500–1000 MET-minutes per week. Similar to the intensity of physical activity, also the target amount of cardiorespiratory physical activity is dependent on individual parameters, such as age and gender, and thus, the range of the recommended amount is wide. (Garber et al. 2011, p. 1336, 1338.)

The amount of physical activity has a dose-response relationship to health benefits. In other words, the greater the amount of physical activity is, the greater the health benefits are. Physically active lifestyle and improved cardiorespiratory fitness reduce the risk to premature death and developing a cardiovascular disease (CVD). (Garber et al. 2011, p. 1338.) In addition to physical health, physical activity has an effect on mental health. Physical activity has been suggested to promote mental health and even prevent from mental disorders. (Saxena et al. 2005)

3 FIRSTBEAT MEASUREMENT

Firstbeat Technologies Ltd provides analysis of well-being based on physiological HRV measurement. The measurement results are analyzed by Firstbeat Lifestyle Assessment software. About 20 000 Finnish employees have voluntary participated in measurements in the occupational health care campaigns conducted in various Finnish companies between years 2000–2013. Originally, the measurement has been conducted for providing employees information about their well-being and not for scientific purposes. However, the participants have been informed by their employers about the agreement, between Firstbeat Technologies Ltd and the occupational health care unit, which provides Firstbeat Technologies Ltd the right to store the measurement results in an anonymized form and use them for the development and research purposes. In this thesis, the anonymous measurement results are formed into a database describing the well-being and lifestyles of working-age Finns.

3.1 Measurement procedure

The Firstbeat measurement procedure has been modified over the years but all their measurements include background information of the subjects and the results of HRV measurements. In addition to the background information questionnaire and the results of HRV measurement, the measurement procedure nowadays includes also a pre questionnaire and keeping a diary during the physiological measurement.

Before the physiological measurements, the subject fills in background information and pre questionnaires. The background information questionnaire gives identifying details of the subject, such as name, date of birth, weight, height and sex (see Background Information Questionnaire in Appendix A). Moreover, in the background information questionnaire, the subject is asked to estimate their contemporary level of physical activity i.e. activity class (AC) on scale of zero to ten. The pre questionnaire includes statements regarding the subject’s physical activity, stress, recovery, eating habits, alcohol consumption, sleep and overall well-being (see Pre Questionnaire in Appendix B). The scale of answers is ‘completely disagree’, ‘partially disagree’, ‘cannot say’, ‘partially agree’ and ‘completely agree’.

The physiological measurement is performed with Firstbeat Bodyguard device or Firstbeat Bodyguard 2 device. The measurement device is attached to skin with two electrodes: one is attached to the left side of the body and the other is attached under the collar bone on the right side of the body (Figure 3.1). Using these two electrodes, the device continuously records beat-to-beat heart rate i.e. R-R intervals. The sampling frequency of the device is 1 000 Hz (Firstbeat Bodyguard Quick guide), which is optimal since according to the recommendations in the HRV measurement the sampling frequency of the measurement device should be at least at least 250 Hz (Task Force 1996, p. 359). In addition to the beat-to-beat heart rate data, Firstbeat Bodyguard 2 device, which was released in spring 2013, records movement data by its accelerometer. However, the accelerometer data is not included to the results of this database.

Figure 3.1. *A properly attached Firstbeat Bodyguard device by which the physiological measurements are performed* (Firstbeat Bodyguard 2 Quick Guide).

The HRV measurement is performed as real-life monitoring. The lightweight measurement device does not restrict daily life and thus the subject can live their everyday life during the measurement. Because the measurements are conducted in free-living conditions, the subject is primarily responsible for supervising the measurement. The battery lifetime of the device is about six days so the device should be able to record for three days without charging. The subject can observe the performance of the measurement device by the light on the measurement device. A green light is blinking on the device as it is measuring. The light is shut down as the device stops measuring. The device should be stopped only when showering or bathing.

The measurement is typically taken for three days, including two working days and a day off from work. The measurement is instructed to be started in the first day at the time of wake up and to be ended in the fourth day at the time of wake-up. During the physiological measurement the subject is asked to keep a diary of their doings. Doings can be, for instance, watching TV or exercising, but especially, working and sleeping times are asked. Moreover, the subject is asked to write down the amount of alcohol consumed during each day of the measurement.

As the HRV measurement results have been analyzed by Firstbeat Lifestyle Assessment software, the subject receives a report of the measurement results. The results are illustrated primarily with graphs in the report. The report includes both an overview of the measured days as well as more detailed results about stress, recovery and physical activity. The overview of a measured day includes HR, the distributions of stress, recovery and physical activity as well as the diary entries. An example of the measurement day's overview is shown in Figure 3.2.

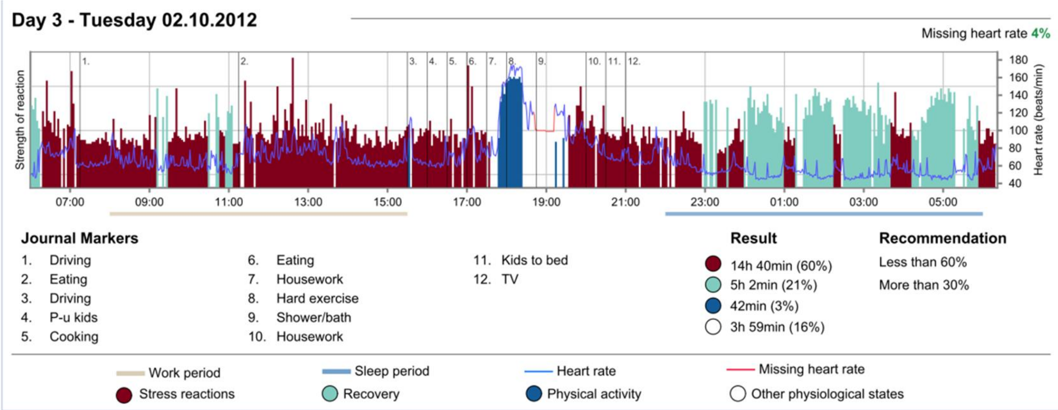
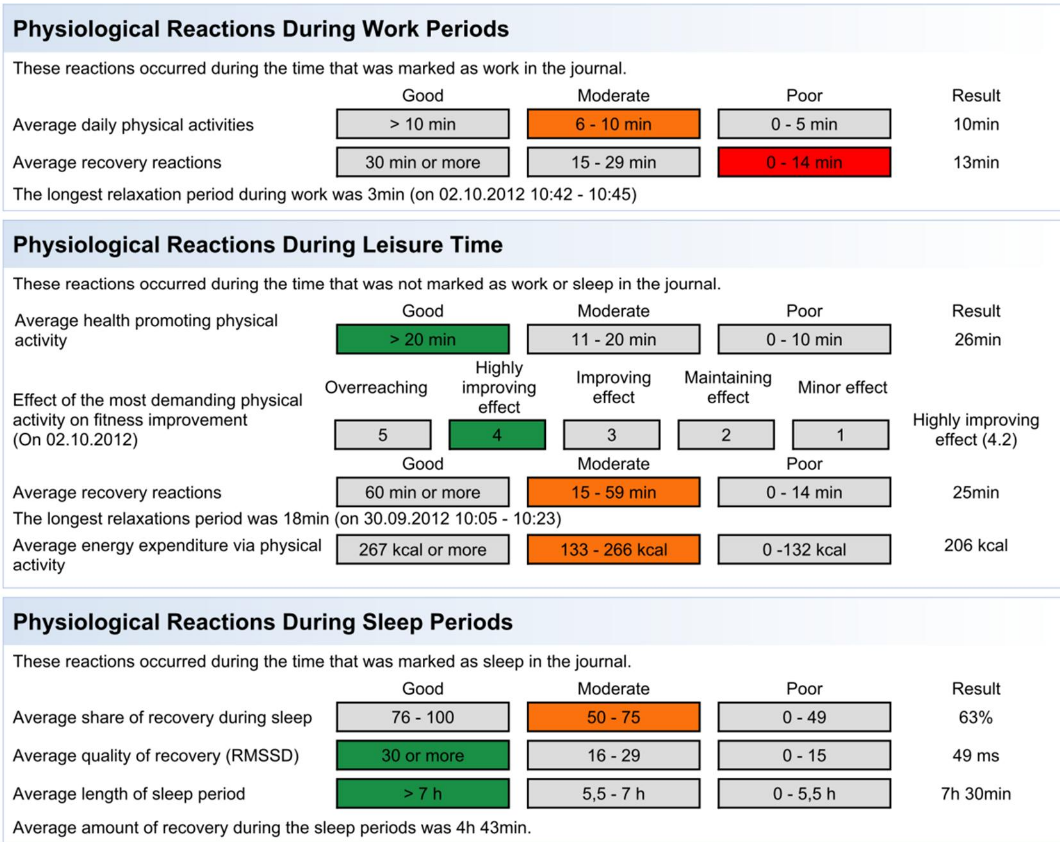


Figure 3.2. *An example of the measurement day's overview in the Firstbeat Lifestyle Assessment report* (Stress and Recovery Overview).

The report includes also more detailed results of stress, recovery and physical activity during the measurement. In the more detailed results, the measured values of stress, recovery and physical activity are compared to their recommended values. An example of Lifestyle Inspection which reveals the state of well-being in the Lifestyle Assessment report is shown in Figure 3.3.



Physiological Reactions During Work Periods

These reactions occurred during the time that was marked as work in the journal.

	Good	Moderate	Poor	Result
Average daily physical activities	> 10 min	6 - 10 min	0 - 5 min	10min
Average recovery reactions	30 min or more	15 - 29 min	0 - 14 min	13min

The longest relaxation period during work was 3min (on 02.10.2012 10:42 - 10:45)

Physiological Reactions During Leisure Time

These reactions occurred during the time that was not marked as work or sleep in the journal.

	Good	Moderate	Poor	Result
Average health promoting physical activity	> 20 min	11 - 20 min	0 - 10 min	26min

	Overreaching	Highly improving effect	Improving effect	Maintaining effect	Minor effect	
Effect of the most demanding physical activity on fitness improvement (On 02.10.2012)	5	4	3	2	1	Highly improving effect (4.2)

	Good	Moderate	Poor	
Average recovery reactions	60 min or more	15 - 59 min	0 - 14 min	25min

The longest relaxations period was 18min (on 30.09.2012 10:05 - 10:23)

Average energy expenditure via physical activity	267 kcal or more	133 - 266 kcal	0 -132 kcal	206 kcal

Physiological Reactions During Sleep Periods

These reactions occurred during the time that was marked as sleep in the journal.

	Good	Moderate	Poor	Result
Average share of recovery during sleep	76 - 100	50 - 75	0 - 49	63%
Average quality of recovery (RMSSD)	30 or more	16 - 29	0 - 15	49 ms
Average length of sleep period	> 7 h	5,5 - 7 h	0 - 5,5 h	7h 30min

Average amount of recovery during the sleep periods was 4h 43min.

Figure 3.3. *The results of physiological measurements compared to the recommended values in the Firstbeat Lifestyle Assessment report* (Lifestyle Inspection).

The purpose of the Lifestyle Assessment report is to provide subjects comprehensible information about different aspects of well-being i.e. stress, recovery and physical activity. The comparison between the measured values and the recommendations helps the subject to comprehend their current well-being status.

3.2 Firstbeat interpretation of the measured HRV data

Firstbeat Technologies Ltd. has implemented a method to correct the artefacts in the measured heart rate data before the analyzing the measured heart rate data. The artefact correction method is based on the assumption that the consecutive RR intervals have similar durations. The potentially artefactual segments, which are detected from too short or too long RR interval durations compared to their neighbors, are extracted from the original signal. The adjacent potentially artefactual segments are compiled before continuing the artefact correction procedure. From the duration of the RR intervals in the potentially artefactual segments, the method computationally concludes whether the potentially artefactual segment includes missing or extra beats. The missing and extra beats are corrected by minimizing the average error among the corrected RR intervals to their neighbor intervals. At last, the method evaluates its performance by comparing the average error among the corrected RR intervals to their neighbors and the average error among the recorded RR intervals to their neighbors. If the corrected RR interval has smaller average error than the originally recorded RR interval, the original RR interval in the artefactual segments is replaced with the corrected RR interval. Otherwise, the recorded RR interval is not changed. The method also saves information of which are the corrected RR intervals in the artifact corrected time series. (Saalasti et al. 2004.)

Based on the measured and artefact corrected HRV data, the Firstbeat Lifestyle Assessment software produces second-by-second information about bodily functions. The software exploits novel methods for analyzing the HRV data developed by Firstbeat Technologies Ltd (Firstbeat Technologies 2007; Firstbeat Technologies 2005; Firstbeat Technologies 2005). All methods utilize only the measured HRV data and some background information of the subject, such as weight, gender and AC. The most important information, which can be derived from the measured HRV data by the Firstbeat methods, considers oxygen consumption, energy expenditure and physiological states of the body, such as physical activity, stress and recovery.

The developed method for estimating oxygen consumption (VO_2) is based on HR level, respiration rate and on/off-response information of oxygen consumption which are derived from the measured HRV data. Also background parameters of maximum heart rate (HR_{max}) and maximum oxygen consumption (VO_{2max}) are taken into account in the estimation of VO_2. The subject's HR_{max} and VO_{2max} values are based on measurements or they are calculated based on formulas (Firstbeat Technologies 2005). Estimated VO_2 can be presented as MET values by dividing the obtained estimation of VO_2 with a constant value of 3.5 (Firstbeat Technologies 2007) as the oxygen consumption at rest is estimated to be 3.5 ml/kg/min (2008 Physical Activity Guidelines for Americans, p.53).

The estimated VO_2 is further utilized in the estimation of EE. In addition to estimated VO_2, the neural network model of the energy expenditure estimation rules in body's metabolism and the subject's weight and calculated or measured VO_{2max}. Respiration quotient and caloric equivalent are used for accessing the metabolic events of the body. (Firstbeat Technologies 2007.) The maximal oxygen consumption is estimated based on an equation introduced by Jackson et al. (1990) which estimates the relation between the maximal oxygen consumption of the subject and the subject's AC, age, BMI and gender.

In Firstbeat Lifestyle Assessment software, the classification of body's physiological state is implemented basically by comparing the degree of cardiac activity to concurrent physical metabolic requirements. The degree of cardiac activity is assessed by comparing HR, HRV, HF and LF to their baseline values, whereas physical metabolic requirements are assessed by HR-derived VO_2 and EE.

In Firstbeat interpretation, the categories of physiological states are physical exercise, light physical activity, recovery from physical exercise, postural change, recovery and stress. If the state of the body cannot be classified into any of these categories, the physiological state of the body is unrecognized. Table 3.1 presents the HR level implicating cardiac activity and the VO_2 level implicating metabolic requirements of the body during different physiological states. (Kettunen & Saalasti 2008.)

Table 3.1. *The degree of HR and VO_2 levels during different physiological states. The plus sign (+) refers to increased level, the minus sign (–) refers to decreased level and the plus minus sign (±) refers to unchanged level as HR and VO_2 levels are compared to their baseline. The number of pluses and minuses indicates the degree of increase and decrease, respectively.*

Physiological state	*HR level*	*VO_2 level*
Physical exercise	+++	+++
Light physical activity	++	++
Postural changes	+	+
Recovery from physical exercise	+ or ±	+ or ++ or +++
Recovery	–	±
Stress	+ or ++ or +++	±

Any physical activity has at least certain duration and during it both cardiac activity and metabolic requirements are increased. Physical activity is further categorized into postural changes, physical exercise and light physical activity. The indicator of postural change is “relatively fast increase and decrease of HR level”. Physical exercise and light physical activity are differentiated based on the intensity level of physical activity. The proportional intensity of physical activity can be estimated using, for instance, information of current VO_2, VO_{2max} level, respiration activity and HRV. Physical exercise is defined as physical activity with high enough (e.g. more than 50% of VO_{2max}) intensity level, whereas in light physical activity the intensity level of physical activity is low (e.g. less than 30% of VO_{2max}). (Kettunen & Saalasti 2008.)

During recovery from physical activity, VO_2 is excess compared to the level of VO_2 at rest (Firstbeat Technologies 2005). Moreover, recovery from physical exercise is possible only after physical activity (Kettunen & Saalasti 2008).

Stress and recovery have similar VO_2 levels but they are distinguished based on cardiac activity. During recovery HR level decreases whereas during stress HR level increases. Consequently, stress is a physiological state of the body where the cardiac activity is increased without any metabolic reason. (Kettunen & Saalasti 2008.)

3.3 Variables of the measurements

The measurement results were preprocessed by Firstbeat Technologies Ltd before constructing the database. The preprocessing of the measurements was designed in collaboration with Firstbeat Technologies Ltd. The purpose of preprocessing the measurements is to anonymize the subjects and decrease the amount of data. The different kinds of variables in the preprocessed measurements are depicted in Figure 3.4. This information about the measurements (shown in Figure 3.4) will be included to the database. The background variables describe the subject characteristics and they are obtained from the background information and pre questionnaires. Because all the measurements are performed in free-living conditions, only the diaries of the subjects can provide information about the events of the measured days. The HR data is analyzed by Firstbeat Lifestyle Assessment software which produces information about the subject’s stress, recovery and physical activity during the measurement. Moreover, the results of the physiological measurement include the original HR and HRV signals as well as a signal representing the detected artefact percentage in the HRV measurements. These signals implicate the start and end times of the measurement.

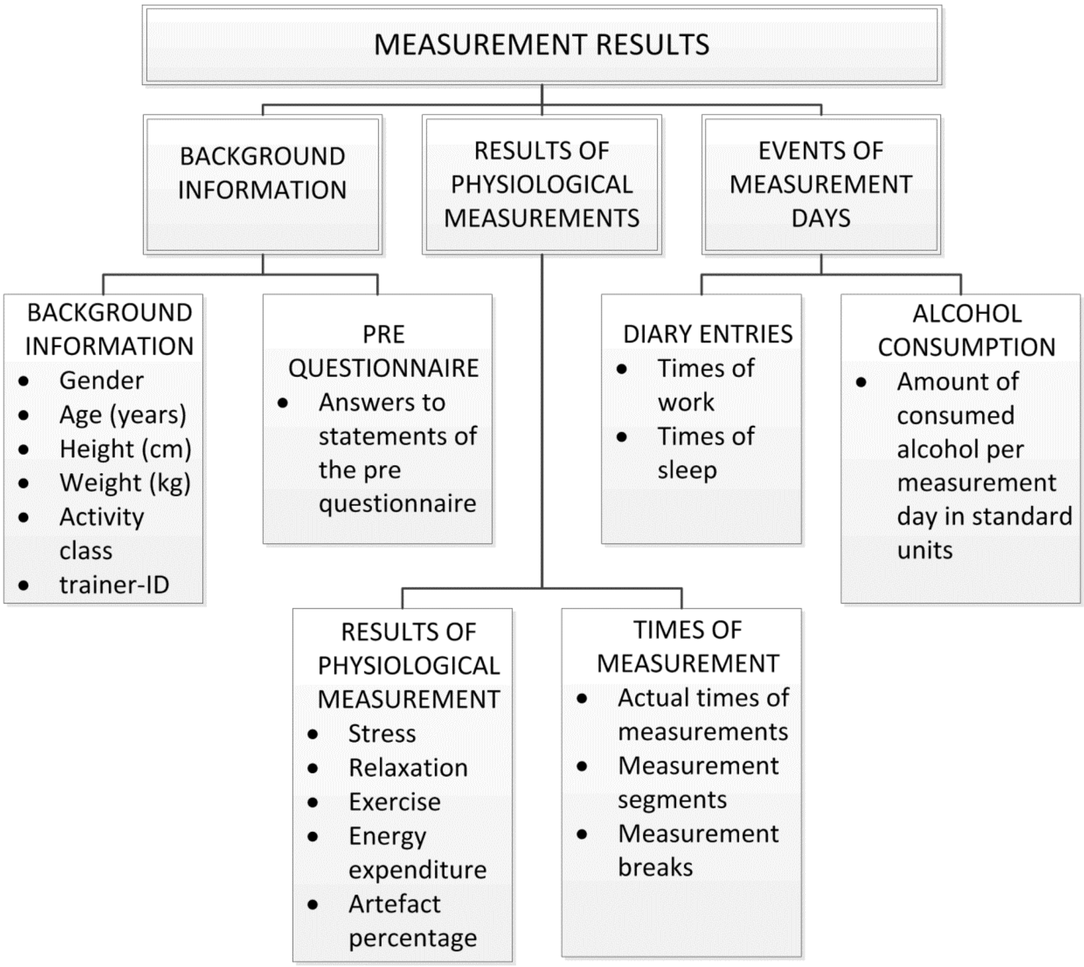


Figure 3.4. *The information available about each preprocessed measurement.*

3.3.1 Background information

All available background information is extracted from background information and pre questionnaires, but the subjects are anonymized. The background data is anonymized by removing identifying parameters, such as name and date of birth. Thus, the only parameter, which can be reliably used for collecting all the measurements of a subject, is the ‘trainer-ID’. The ‘trainer-ID’ consists of numbers and letters and it is unique for each subject. In other words, the purpose of the ‘trainer-IDs’ is to identify the measurements of the same subject. However, there are some measurements which do not includes the ‘trainer-ID’.

In the preprocessed measurements, background information consists of background parameters and answers to the pre questionnaire. The background parameters of subjects comprise gender, age in years, weight in kilograms, height in centimeters, activity class and ‘trainer-ID’ (Figure 3.4). The pre questionnaire results comprise the subjects’ answers for each of the ten statements in the personal pre questionnaire. The statements of the pre questionnaire and the scale of answers are available in Appendix B.

3.3.2 Events of measured days

Events of measured days are gathered from subjects' diaries and their reported amount of consumed alcohol. In the preprocessed measurements, diary entries include only the reported start and times of work and sleep (Figure 3.4). In other words, other doings reported in diaries are not saved in the preprocessed measurements. Sleep time starts as the subject goes into bed and actually tries to sleep and sleep time ends as the subject wakes up. Working time starts as the subject starts working and ends as the working ends. Free time is assessed based on reported times of sleep and work: time which is neither sleep nor work is regarded as free time.

A measurement day is defined to start at the time of waking up and end at the time of next wake-up. In the preprocessed measurements, the information of consumed alcohol portions is based on a subject's self-reports for each measurement day (Figure 3.4). The amount of consumed alcohol is measured in Finnish standard units. A Finnish standard unit includes 12 grams of ethanol.

3.3.3 Physiological measurements

Originally, Firstbeat Lifestyle Assessment software produces second-by-second information of physiology i.e. the physiology of the body is presented as signals with a sampling period of one second. However, in the preprocessing of the measurements the original signals are resampled in order to decrease the amount of data but still to preserve the good quality of the data. The resampling of the original signals was designed in collaboration with Firstbeat Technologies Ltd and it was implemented by Firstbeat Technologies Ltd for the original signals produced by the Lifetyle Assessment software. Moreover, the preprocessed measurements include single variable values which are calculated from the measured HR data by Firstbeat algorithms. For example, health benefits of physical activity are estimated by Firstbeat algorithm which produces a single value for the health benefits of the physical activity during the measurement.

The measured HR data and HR-derived variables, such as HRV parameters, physiological states, MET values, energy expenditure and detected artefact percentage in the measured RR intervals, are presented in the preprocessed measurements as discrete signals in time domain. These signals are selected and resampled from the original signals produced by Firstbeat Lifestyle Assessment software. The values of the discrete time signals represent the average of the original signal values in the sampling period. The sampling period varies according to the variable which the signal represents. For most of the signals a sampling period of 10 minutes was considered adequate. Moreover, the synchronism between the signals of different measurements varies. Signals having uniform start and end times of sampling periods from measurement to measurement are called as synchronous signals, while signals having measurement specific start times for the sampling periods are called as non-synchronous signals. The signals, their descriptions, sampling periods and synchronisms are introduced in Table 3.2.

Table 3.2. *From the measured HR derived signals, their descriptions, sampling periods, units and the synchronism between the signals of different measurements.*

Variable	*Sampling period*	*Synchronism*	*Unit*	*Description*
ARTEFACT	10 min	Synchronous	%	A signal representing the detected artefact percentage in the measured RR interval data.
HR	10 min	Synchronous	bpm	A signal representing heart rate. The signal is derived from the artefact corrected RR interval data.
LF	10 min	Synchronous	ms^2	A signal representing the spectral power in the low frequency regions of the HRV. The signal is derived from the artefact corrected RR interval data.
HF	10 min	Synchronous	ms^2	A signal representing the spectral power in the high frequency regions of the HRV. The signal is derived from the artefact corrected RR interval data.
RMSSD	10 min	Non-synchronous	ms	A signal representing HRV as RMSSD values. The RMSSD signal values were calculated from the artefact corrected RR interval data using a five minute time window.
MET	30 sec	Non-synchronous	MET	A signal representing MET values. The MET values are derived from the artefact corrected RR interval data by the Firstbeat method which estimates the VO_2.
EE	1 h	Synchronous	kcal/min	A signal representing energy expenditure. The values of energy expenditure are derived from the artefact corrected RR interval data by the Firstbeat method which estimates the VO_2.
STATE	10 min	Synchronous	%	A set of signals each of which represent a physiological state of the body. The physiological states of the body are derived from the artefact corrected RR interval data by the Firstbeat method which categorizes the physiological states.

Basically, in order to resample the original signals, the original signals are divided into non-overlapping successive time windows. The duration of each time window is equal to the sampling period. Once the original signal is segmented, the average of variable values in each signal segment is calculated. Thus, these average variable values are samples of the resampled signal and each sample of the resampled signal represents the average value of the variable during a sampling period.

In order to synchronize STATE, HR, HF, LF, ARTEFACT and EE signals of all measurements, in the resampling the original signals are segmented into predefined time windows. As the sampling period is ten minutes, each hour of the measurement is separated into following time windows: the first time window of each hour considers the first ten minutes of the hour , the second ten-minute time window considers the hour from ten past to twenty past etc. As the sampling period is one hour, time windows are set to start at the hour and end at the next hour. Thus, these signals of all measurements are in temporal consistence. On the other hand, as a consequence of synchronization of the other samples, the durations of the first and last time windows vary from measurement to measurement.

The MET and RMSSD signals of different measurements are not synchronized as the original signals are resampled. In other words, the first time window starts at the start of the measurement, and thus, the start and end times of sampling periods vary from measurement to measurement. Moreover, the duration of the last time window is shorter than the sampling period of other samples if the measurement duration is not a multiplication of the sampling period.

An example of signals is illustrated in Figure 3.5. All the signals are obtained from a measurement of a 34-year old male who is normal weight and has an AC of six. The measurement has included diary entries of work and sleep. The measurement has started in the morning at around seven o'clock and ended in the next morning at quarter to eight. During the measurement, the subject has been working from half past eight until half past four and sleeping from quarter to eleven until half past seven. The working and sleeping periods are marked in the figures.

The HR, LF, HF and RMMSD signals provide information about the HRV. The MET and EE signals reflect the oxygen consumption of the subject. The ARTEFACT signal is reflecting the detected artefactual RR intervals in the measured HR signal. The signals included into STATE signals represent stress, relaxation, light and heavy physical activity, exercise recovery and unrecognized physiological state. In other words, the STATE signals together represent the physiological states of the body which are based on the Firstbeat's interpretation of the measured HR data.

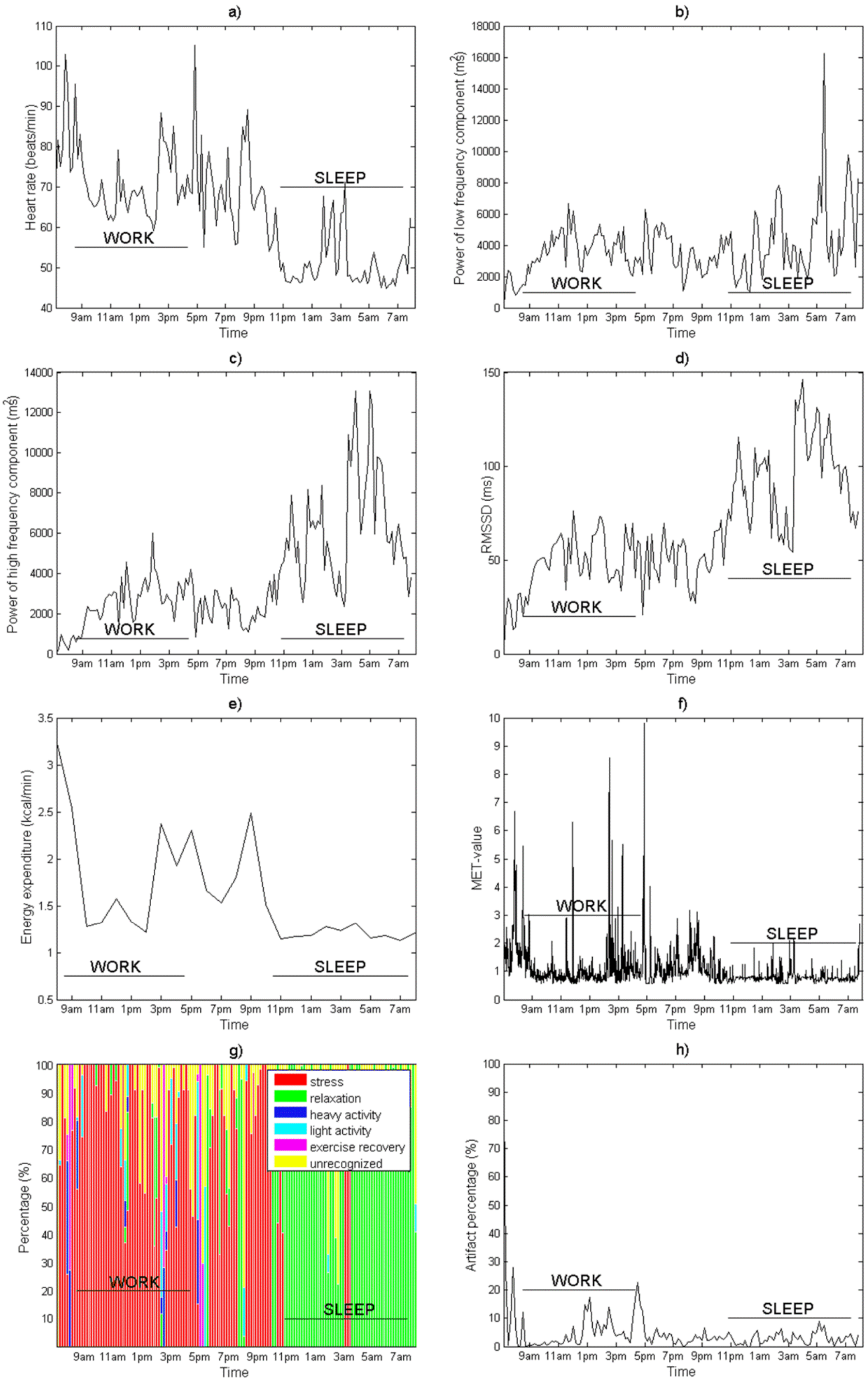


Figure 3.5. *Examples of the signals. The figures and their signals are: a) HR, b) LF, c) HF, d) RMSSD, e) EE, f) MET, g) STATE and h) ARTEFACT.*

4 PROCESSING THE DATABASE

The preprocessed measurements are arranged into a uniform database in which the preprocessed measurements are presented as measurement days. Each measurement day represents a natural circadian rhythm of the subject. Because some of the preprocessed measurements were broken i.e. the three-day measurement of the subject was splitted into multiple measurement segments, the measurement segments were compiled to cover the whole measurement period of the subject before separating the preprocessed measurements into measurement days. The processing of the preprocessed measurements into a uniform database was performed using MATLAB R2013a. In the database, the measurement days has the information described in in Figure 3.4 in Section 3.3.

4.1 Broken measurements

The Firstbeat Bodyguard and Firstbeat Bodyguard 2 measurement devices started a new measurement i.e. a measurement break occurred always when the device was unattached for long enough or the battery ran empty. The reasons for measurement breaks varied and they could not be traced afterwards. Presumably, the most common reasons for measurement breaks were related to detachment or low battery of the measurement device. As described in Section 3.1, primarily the subject was responsible for supervising the measurement. The measurement device might have to be detached on purpose because of skin irritation caused by the electrodes, for example. On the other hand, the measurement device might also be detached inadvertently. For instance, the subjects were not able to supervise the measurement device’s performance by the light during their sleep.

The measurement of a subject was considered to be broken if a subject had more than one segment of measurement. The majority of the subjects did not have a broken measurement. However, about every fourth subject i.e. about 5 500 subjects had more than one measurement segments. Table 4.1 presents how the number of measurement segments was distributed among the subjects.

Table 4.1. *The subjects grouped according to the number of measurement segments in their measurement.*

The number of measurement segments per subject	*The number of subjects*
1	15 452
2	3 287
3	977
4–6	636
≥7	586

The durations of measurement segments varied from less than one hour up to 205 hours. However, most of the measurement segments had duration of 65–80 hours, which is rational because of the observed number of measurement segments per subject and the three-day measurement procedure. Other common durations for measurement segments were 5–10 hours, 20–25 hours and 45–50 hours. Detailed distribution of measurement segments' durations is shown in Figure 4.1.

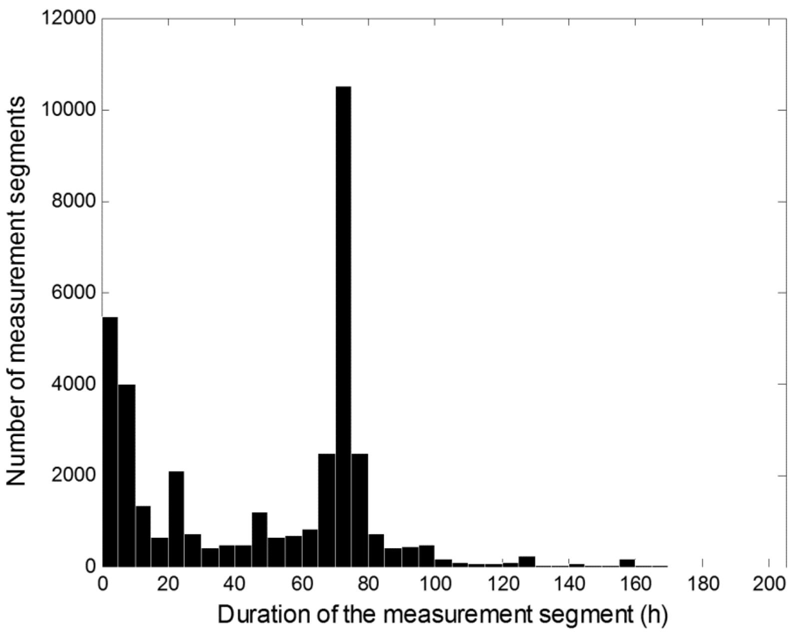


Figure 4.1. *A histogram about the durations of measurement segments.*

Similar to measurement segments, also durations of measurement breaks, i.e. the time between two consecutive measurement segments of a subject, varied. The shortest measurement breaks took only some minutes, while the longest measurement break was several hours. The longest measurement breaks, whose durations were multiple days, were caused by the follow-up measurements and thus, should rather be considered as new measurements. There were also some overlapping measurements. The reason for the overlapping measurements is not known. Overlapping measurements may be a consequence of a measurement which has been analyzed in overlapping time windows. In total there were about 14 700 detected measurement breaks. Table 4.2 shows the percentage of measurement breaks in different measurement break categories.

Table 4.2. *The number of overlapping measurements, measurement breaks and follow-up measurements.*

Measurement break category	*The percentage of all measurement breaks*
Overlapping measurements (duration of a measurement break < 0 h)	8.82 %
Measurement break 0–24 h	37.99 %
Follow-up measurement (duration of a measurement break > 24 h)	53.19 %

In Table 4.2, the follow-up measurements were defined solely based on the duration of a measurement break. In order to precisely determine the number of the follow-up measurements, also the duration of the measurement segments should be considered. Consequently, the number of follow-up measurements showed in Table 4.2 likely overestimates the actual number of follow-up measurements.

4.2 Compiling measurement segments

Because a remarkable part of the measurements were broken, the measurement segments were compiled before separating the measurements into measurement days. Compiling the measurement segments before separating them into measurement days made sure that a measurement day of a subject was not broken into pieces in the database. The information of the overlapping and follow-up measurements was used when designing the algorithms for compiling the measurement segments.

In order to cover the whole measurement of a subject, all the measurement segments of a subject fulfilling certain criteria were compiled. The measurement segments were considered to be possible to compile if they had identical ‘trainer-ID’ and background information i.e. they were measurement segments of the same subject and the time interval between the measurement segments was shorter than or equal to eight hours. The eight hours was defined to be the maximum measurement break because the intention of the database was to present the measurement days of subjects. In other words, the database was supposed to include actually measured days and not measurement days with only some hours of measurement.

Before compiling the results of the measurement segments, the other aspects of the measurement were considered. As the criteria for compiling the measurements was the identical background information, the background information of the compiled measurement was obviously the same as for the measurement segments. The start time for the compiled measurement was the start time of the first measurement segment and the end time for the compiled measurement was the end time of the last measurement segment. In other words, the total measurement time was the time between the start time of the first measurement segment and the end time of the last measurement segment. Also the reported amount of consumed alcohol, the answers of the pre questionnaire and the times of work and sleep per measurement segment were saved as compiling the measurement segments.

In the preprocessed measurements the results of the measurement segments were presented as a set of single variable values and signals. The single variable values were calculated based on the measured segment, whereas the signals covered the whole measurement segment. Most of the variable values could easily be calculated from the signals as well. Consequently, as compiling the measurement segments, the single variable values were abandoned and the measurement results were presented as compiled signals of the measurement segments. However, some of the variables were calculated by Firstbeat algorithms and that's why some single variable values, such as the index about health benefits of physical activity, presented in the preprocessed measurements could not be included to the database.

There were different procedures for compiling synchronous and non-synchronous signals. Non-synchronous signals were compiled based on the time interval between the measurement segments, whereas synchronous signals were compiled based on the predefined time windows. The compiled signals had the same resolution as the signals in the preprocessed measurements.

The non-synchronous i.e. MET and RMSSD signals of the measurement segments were compiled by based on the start and end times of the measurement segments. The start and end times of the sampling periods in non-synchronous signals varied from measurement segment to measurement segment because the sampling periods were dependent on the start time of the measurement segment. Thus, non-synchronous signals could not be compiled without causing a time shift of the signals. In other words, the sampling periods' start and end times did not match in different measurement segments and that's why only the earliest measurement segment did not have any time shift when the measurement segments were compiled. The number of samples during the measurement break was calculated by dividing the time interval between the consecutive measurement segments by the sampling period and rounding it to the nearest integer. This procedure also minimized the unavoidable time shift in the compiled signal and the time shift was always less than or equal to a half of the sampling period. If the measurement segments were for some reason overlapping, the compiled signal values during the overlap were defined to be the average of the overlapping signals' values.

Figure 4.3 shows an example of original MET signals of measurement segments and their compiled MET signal. The measurement pause starts at around 240 seconds and stops after about 370 seconds and during it the compiled MET signal's values are zeroes. Because the measurement pause is not a multiplication of the sampling period, the second measurement segment's MET signal must be shifted in time for the compiled MET signal. The time shift is seen in the Figure 4.2 as the compiled MET signal is about nine seconds ahead of the MET signal of the second measurement segment.

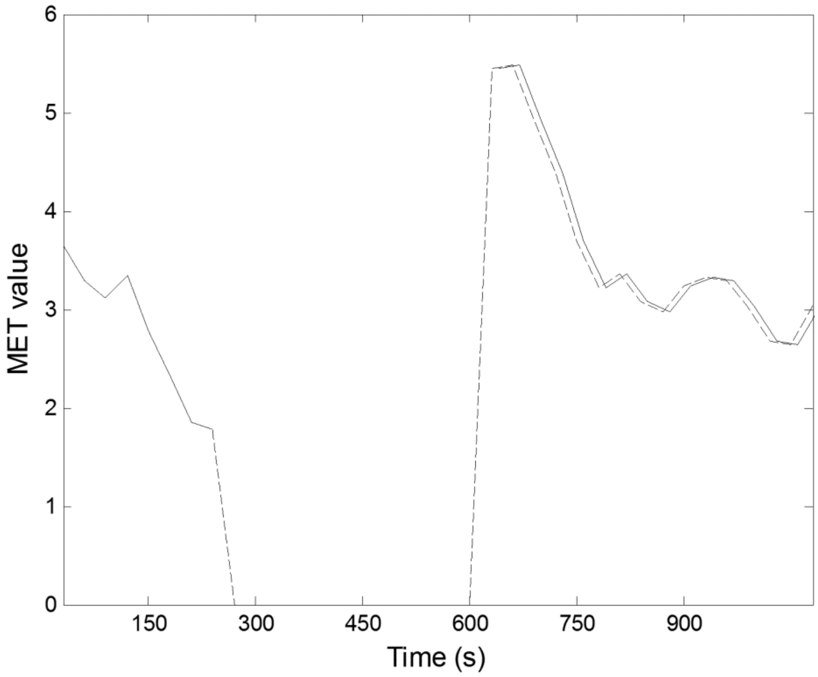


Figure 4.2. *An example of compiled MET signal (dashed line) and the original MET signals (solid lines) of measurement segments.*

In order to compile the synchronous signals i.e. STATE, LF, HF, HR, ARTEFACT and EE signals, the total measurement time was segmented into similar time windows as when resampling the original signals in the preprocessing of the measurements. These time windows were then compared with the sampling periods of measurement segments in order to construct the compiled signal. Figure 4.3 shows a flow chart of the algorithm used for compiling synchronous signals of measurements segments. The algorithm in Figure 4.3 is presented for one time window and the time windows are handled one by one until the total time of the measurement is gone through.

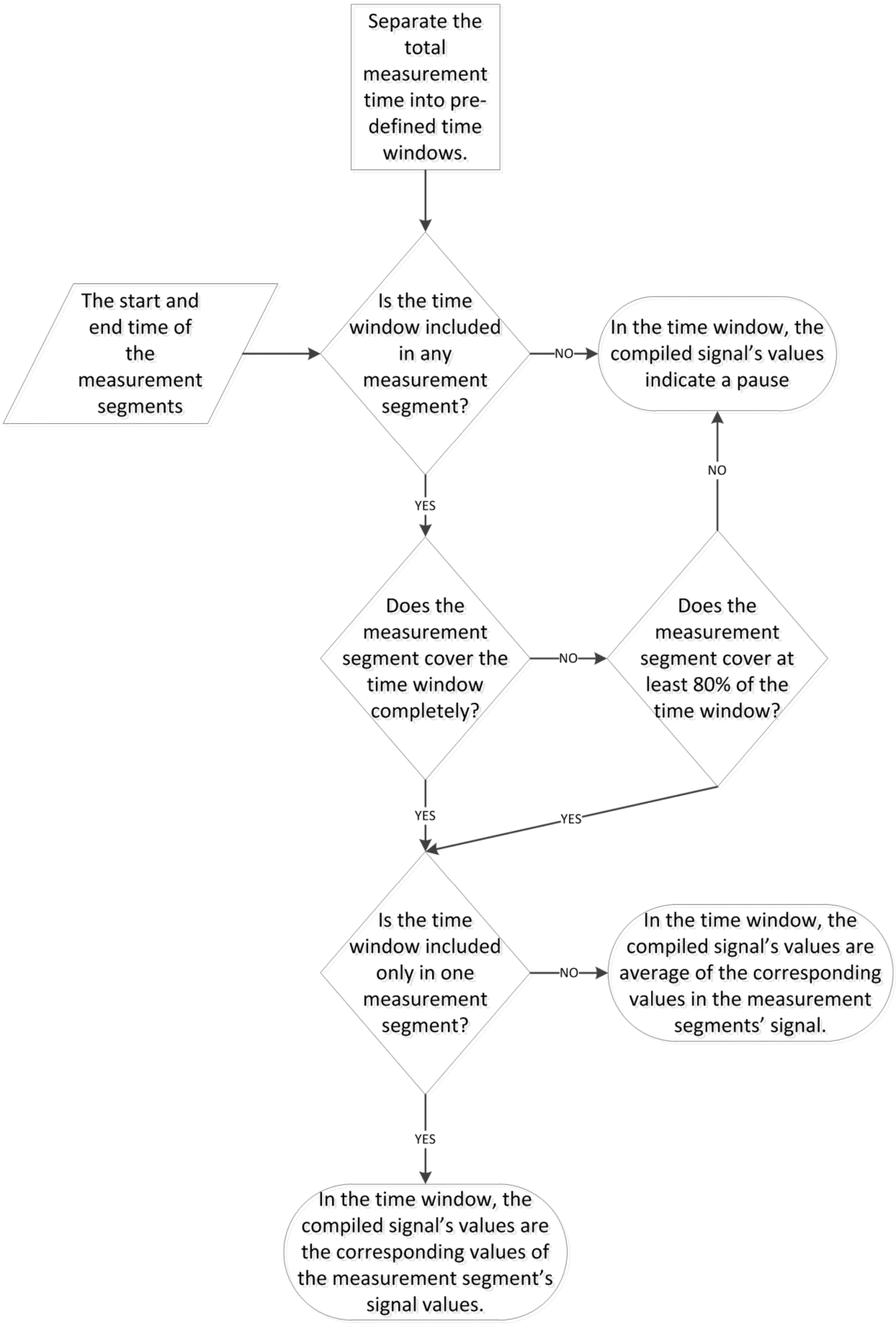


Figure 4.3. *A flow chart of the algorithm for compiling synchronous signals of measurement segments.*

The algorithm included three different results depending on the number of measurement segments into which the time window was included. Some of the time windows were included in one or several measurement segment, whereas the others were not included into any measurement segment. On the other hand, a time window could be included in a measurement segment either totally or partly. The time window was totally included to the measurement segment if the measurement segment has started before or at the start time of the time window and ended after or at the end time of the measurement segment. Otherwise, the time window was only partially included to the measurement segment i.e. the measurement segment had started or ended within the time window.

As the time window was totally included into only one measurement segment, the compiled signal's value was the same as the value of the measurement segment's signal in that time window. If there were no measurement segment, in which the time interval would have completely been included, the measurement segment, in which the time window was only partially included, was considered to reliably represent the compiled measurement in the time window if the measurement segment covered at least 80 % of the time window. Otherwise, the measurement segments were considered to be unreliable in the time window and that's why they were regarded as a pause.

A time window could be included into more than one measurement segment if the measurement segments were overlapping or if the measurement pause between the measurement segments was shorter than the sampling period. The average of the measurement segments' signal values were calculated if the measurement segments were overlapping or if the non-measured time between the measurement segments was shorter than 20 % of the sampling period.

The time windows which were not included into any of the measurement segments were considered as measurement breaks. The compiled signal values during these time windows were set to signal specific values indicating a pause.

4.3 Separating compiled measurement segments into measurement days

The compiled measurements were further separated into measurement days, in order to unify the elements of the database. A measurement day was defined to start at the time of the day's wake up and end at the time of the next day's wake up. If the measurement was lacking of diary entries, the measurement day started in morning at six o'clock and ended in the next morning at six o'clock. Only the start time of the first day of the measurement and the end time of the last day of the measurements were handled exceptionally. The first measurement day was defined to start at the start time of the measurement, whereas the last measurement day was defined to end at the end time of the measurement.

Similar to compiling the measurement segments, separating the compiled measurements considered all aspects of the measurement results. Obviously, each measurement day separated from the compiled measurement had the same background information as the compiled measurement. From the compiled measurement only the diary entries and the amount of consumed alcohol considering the particular measurement day were taken into account.

The compiled signals were separated into measurement days according to the start and end times of the measurement days. Firstly, the total time of compiled measurement was separated into time windows with the duration of the signal's sampling period. In other words, the measurement day was separated into time windows similar to the time windows when resampling the signals in preprocessing or compiling the signals of measurement segments. Thereafter, the time windows were compared to the time windows of the signal. The time windows of signals identical to the time windows of the measurement day were regarded to represent that time window in the measurement day. However, the first and last time windows of measurement days may differ from the signals' time windows because the waking up may have occurred within a sampling period. Thus, a sample of the signal may be included to two measurement days. In the first measurement day the sample is the last and in the second measurement day the sample is the first.

As a result of separating the compiled measurement days, each compiled measurement is separated into one or several measurement days, which represent the circadian rhythm of the subject. The measurement days form the database and the information about measurement days in the database is shown in Figure 3.4 in Section 3.3.

4.4 Technical preprocessing

To ensure the good quality of the data, the measurement results in the database were preprocessed before further analysis. Most importantly, preprocessing considered removing the replicated measurements, ensuring the proper length of the signals and validation of their variable values.

The replicated measurements were detected by comparing the dates of measurement days, their background information and their 'trainer-IDs'. If two or more measurement days started at the same time and the background information and the 'trainer-IDs' of these measurement days were also identical, the measurements were interpreted to be replicates of each other. Only one measurement of each set of replicated measurements was taken into account when forming the final dataset.

In addition to removing the replicated measurements, the lengths of the signals were ensured. The signal lengths were compared to the calculated signal lengths which were regarded as proper ones. The proper signal length was calculated based on the start and end time of the measurement and the sampling period of the signal.

If the length of the signal did not match to its proper length, some samples were added to the signal or taken out from the signal. Usually, the signal lengths differed by one sample. The difference between the actual signal length and the proper signal length was most probably a consequence of the algorithm calculating the resampled signals. Most commonly, the signal included one sample too much if the measurement has stopped few seconds before the next sampling period or if the measurement had started few before the first sampling period. On the other hand, the signal lacked one sample if the measurement had stopped few seconds after the end of the last sampling period or if the measurement had started few seconds before the first sampling period. In the case of extra sample, the first or last sample was removed from the signal and in the case of a missing sample, the missing sample was added as the signal's first or last sample. The value of the missing sample was replaced with the value of the next or previous sample.

4.5 The structure of the database

The database is the set of technically preprocessed measurement days. Apart from the single variable values in the results of the physiological measurements, the measurement days in the database include the same information about the measurements as the preprocessed measurements (described in Section 3.3). Altogether, there were about 86 000 measurement days in the database which were measured from about 21 500 subjects.

The measurement days in the database can also be organized according to the subjects. In other words, the measurement days' information about the background parameters and the 'trainer-ID' of the subject are used for finding all the measurement days of a subject. In this structure, all the measurement days of the same subject form an element of the database.

Consequently, the database can be studied at measurement day level as well as at individual level. The research question defines the level which is used for studying the database.

4.6 Graphical user interface for analyzing the database

A graphical user interface (GUI) was designed for basic statistical analysis of the database. The user can examine the database at measurement day level or individual level. Considering the database as measurement days, each measurement day represents an element in the database. As the dataset is considered by individuals, the average of the subject's measurement days is regarded as an element of the dataset. The statistical parameters are calculated for the variable and measurement period the user selects. Moreover, the user can restrict the dataset from which the results are calculated by giving some inclusion criteria for the measurements. The inclusion criteria may concern either the measurement or the subjects or both of them. The inclusion criteria related to the measurement are the duration and the maximum artefact percentage of the measurement, while the inclusion criteria related to subjects are gender, age, BMI and AC.

As a result, the GUI calculates basic statistical parameters of variable values during the selected measurement period from the measurements which fulfill the inclusion criteria set by the user. The GUI also enables the user to look at the distribution of the variable values in different subsets of measurements. Figure 4.4 shows the start window of the graphical user interface in which the user can set the variable and the measurement period under interest and the inclusion criteria for measurements.

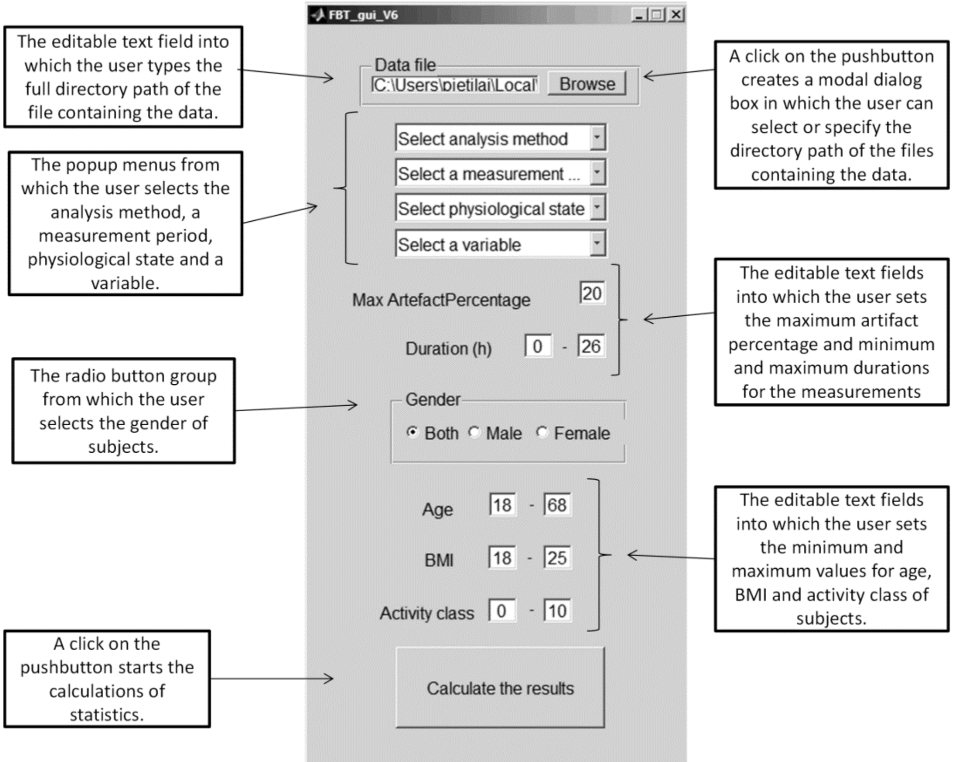


Figure 4.4. *The graphical user interface for assessing the Firstbeat database.*

Firstly, the user selects the file which contains the database and the method for analysis. The measurement period is selected from the second uppermost popup menu and the alternatives are the whole day, working time, free time and sleeping. These measurement periods are based on the times marked in the subject's diary. For day, work and free time the user can look at the physiological states of exercising, stress and recovery, whereas for sleep the only meaningful physiological states are stress and recovery. According to the selected physiological state, the popup menu of 'Select a variable' lists the variables related to the selected physiological state. These variables are variables which Firstbeat calculates from the measurements with the Lifestyle Assessment software. The GUI calculates the variable values from the measurement signals based on the Firstbeat's definitions of the variables.

After selecting the measurement period and the variable, the user may set inclusion criteria for measurements. The inclusion criteria may consider the measurement as well as the background parameters. The inclusion criteria related to the measurement, which the user can set, are the lower and upper limits for the duration and the maximum artefact percentage of the measurement. Considering the background parameters, the user can select the gender and set lower and upper limits for age, BMI and AC.

As the inclusion criteria and other input parameters are set, the GUI calculates the statistics and shows them in a new window. The layout of the result window differs according to the selected analysis method. If the data is considered as measurement of individuals, the result window does not include the number of measurement days. Otherwise, the result windows are the same. An example of the result window of data analyzed by measurement days is shown in Figure 4.5.

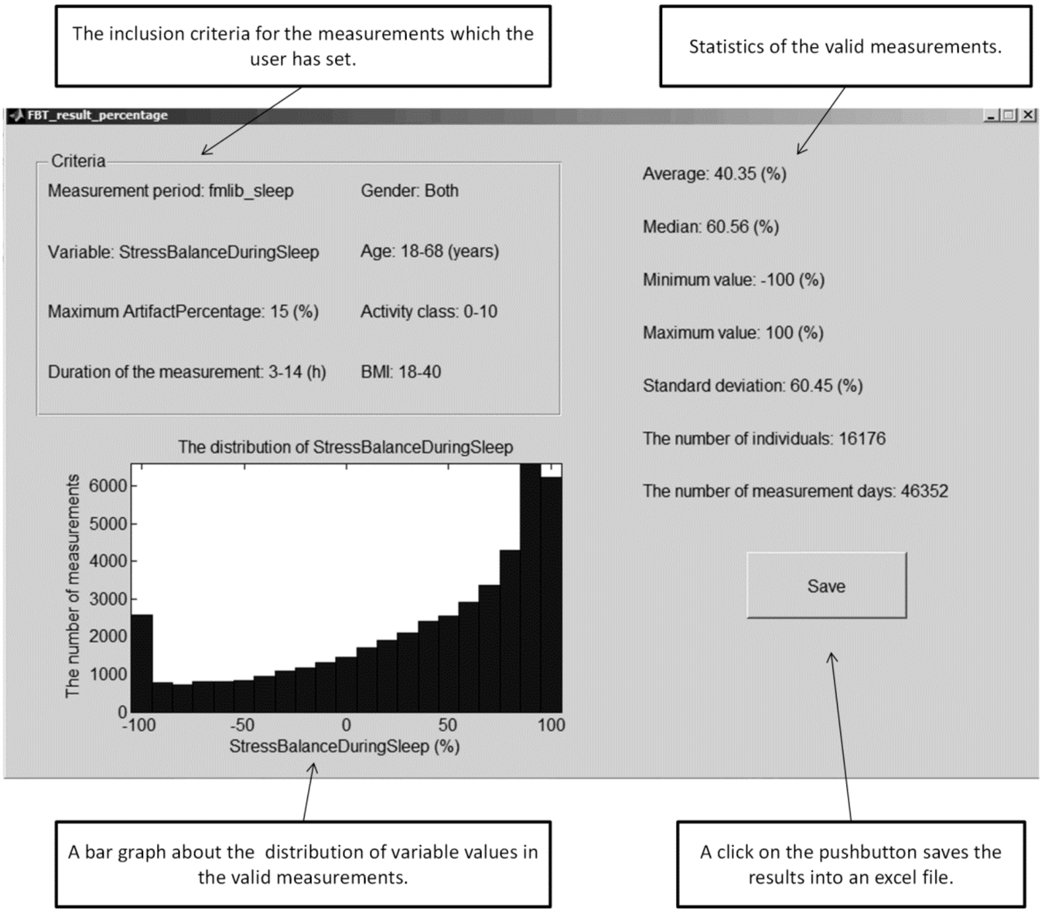


Figure 4.5. *The result window of the GUI for assessing the database.*

The result window presents the selected variable, measurement period and inclusion criteria in the upper left corner of the window. The calculated statistical parameters i.e. arithmetic mean, median, standard deviation, maximum and minimum values of the variable and the amount of data are presented on the right side of the window. Moreover, the result window includes a graph about the distribution of the variable values.

The 'Save' button saves the data of the result window as an excel file. Besides all the results, which are presented in the result window, also the demographics of the data and the percentiles (10%, 25%, 50%, 75% 90%) of the variable values are written in the excel file.

5 RESULTS

The database includes plenty of information of physiology of the subjects during their measurement. In this Chapter, the descriptive statistics and results on pre questionnaire results, HRV parameters, stress, quality of sleep and physical activity are reported. Moreover, the correlations between the results and the subjects' background parameters are calculated and the correlation coefficients with p-value lower than 0.05 were regarded as statistically significant. The great number of Finnish working-age subjects allows considering these results also in different background parameter based groups of subjects. On the other hand, results of stress, physical activity and average daily profiles of physiological states are compared between working days and days off. The statistical similarity in the results of the different groups of subjects, and between working days and days off, is assessed by the Kruskal-Wallis test and the risk level of 5% is used to assess the statistical significant difference. Furthermore, the results of the pre questionnaire are compared to the results of the physiological measurements, which provides information about the differences in the subjective and objective measurement results.

5.1 Inclusion criteria

The following inclusion criteria are used for this database in order to enhance the quality of the data. The inclusion criteria consider time of the measurement, duration of the measurement, background parameters and detected artefact percentage during the measurement.

Firstly, only the measurements conducted during years 2007–2013 were taken into account since only 0.35 % of the measurement was conducted before 2007. Moreover, only the measurement days with duration of longer than or equal to 16 hours were included since the measurement days were intended to describe the entire day. This criterion fulfills the duration recommendation of five minutes for the short-term HRV measurements but it does not fulfill the duration recommendation of 24 hours for the long-term HRV measurements (Task Force 1996, p. 355). However, as shown in Section 4.1. most of the measurement days' durations were longer than or equal to 24 hours.

The background variables considered in the inclusion criteria are age and BMI. The aim was to study Finnish working-age population and therefore the inclusion criterion for age was 18–65 years. BMI was restricted to be 18.5–40 kg/m^2 because there is a doubt about the feasibility of the HRV measurement in underweight and obese people, at least when assessing stress (Hyvinvointia työstä).

The average artefact percentage of the measurement day was calculated based on the ARTEFACT signal of the measurement day i.e. the percentage of artefactual RR intervals in a 10-minute period. The average artefact percentage was defined to be the average of the 10-minute average artefact percentages from which the measurement breaks were excluded. Table 5.1 describes the calculated average artefact percentages of the measurements days. In Table 5.1 the percentage of the measurement days is calculated from the 56 974 measurement days which fulfilled the above mentioned inclusion criteria considering the year of the measurement, the duration of the measurement, BMI and age of the subject.

Table 5.1. *The average artefact percentages in measurement days fulfilling the inclusion criteria considering age, BMI, the year and the duration of the measurement.*

Average artefact percentage	*Percentage of measurement days (%)*
< 1%	13.3
< 5%	73.2
< 10%	83.4
< 15%	89.2
< 20%	92.0
< 50%	96.8

According to the average artefact percentages, the reliability of the measurement was overall very good since in most of the measurement days the artefact percentage was lower than five. The inclusion criterion for the average artefact percentage was set to be 15 % at maximum even though the reliability of all HRV parameters, except from the RR intervals, has been reported to decrease if the typical measurement error is higher than 10 % (Sookan 2012). However, because there is only about 6 % of measurements with an average measurement error higher than or equal to 10 %, the results of the database can in general be considered reliable.

To sum up, the inclusion criteria which were set for the measurements considered the year of the measurement, BMI and age of the subjects as well as average artefact percentage and duration of the measurement. All the inclusion criteria and their acceptable values are presented in Table 5.2.

Table 5.2. *The inclusion criteria for the measurement days.*

The inclusion criterion	*The acceptable values*
The year of the measurement day	2007–2013
The duration of the measurement day	>16 h
The average artefact percentage of the measurement day	<15 %
BMI of the subject	18.5−40
Age of the subject	18−65

In general, the results of the database which are discussed in this thesis are obtained from the measurement days fulfilling the above mentioned inclusion criteria. However, these inclusion criteria are not applicable for all research questions and thus, there is a mention if the measurement days from which the results are obtained do not fulfill these.

5.2 Demographics

In total there were 50 844 measurement days which fulfilled the inclusion criteria. 82 % of the measurement days included diary entries, whereas 29 % of the measurement days included information about alcohol consumption. The results of pre questionnaire were included in 36 % of the measurement days. The number of measured individuals in the measurement days was estimated based on the subjects' background information, 'trainer-ID' and the measurement date. The measurement days were considered to be measured from the same individual if the background information and the 'trainer-ID' were identical and if the measurements were performed within two weeks. The subjects are divided quite evenly to men and women: 53 % of the subjects were women. Table 5.3 shows the information related to the number of measurement days and individuals.

Table 5.3. *The number and percentages of different kinds of measurement days and individuals.*

	The total number (%)
Number of measurement days	50 844 (100 %)
Number of measurement days including alcohol information	14 620 (28.8 %)
Number of measurement days including diary entries	41 453 (81.5 %)
Number of measurement days including pre questionnaire	18 205 (35.8 %)
Estimated number of individuals	18 736 (100 %)
Women	9 834 (52.5 %)

The demographics are presented separately for men and women in Table 5.4. The mean, standard deviation (SD) and median are calculated for all background parameters. The demographics are calculated based on individuals having at least one measurement day fulfilling the inclusion criteria. In other words, the demographics describe the background parameters on individual level and they are not affected by the subject's number of measurement days. On average, the subjects were middle-aged i.e. their age was between 41 and 60 years and overweight i.e. the average BMI was higher than or equal to 25 kg/m^2 and lower than 30 kg/m^2. However, the average AC of the subjects was five which is quite high considering that the activity classes from eight to ten are meant for athletes or subjects exercising very systematically.

Table 5.4. *The averages, standard deviations and medians of background parameters for men and women.*

Background parameters	*MEN*		*WOMEN*	
	Mean (SD)	Median	Mean (SD)	Median
Age (years)	43.5 (10.1)	44.0	44.1 (10.1)	45.0
Height (cm)	179.9 (6.5)	180.0	166.0 (5.9)	166.0
Weight (kg)	86.1 (13.0)	85.0	70.5 (12.9)	68.0
BMI (kg/m^2)	26.6 (3.5)	26.0	25.6 (4.4)	24.6
AC (scale: 0–10)	5.0 (2.0)	5.0	4.8 (1.9)	5.0

In order to assess the variety in the subjects' background parameters, the subjects were grouped based on their background parameters i.e. gender, age, BMI and AC. Each age group, into which the subjects were classified, represents around a decade. The BMI groups were formed based on the BMI classification of World Health Organization. The subjects with a BMI greater than or equal to 18.5 kg/m^2 and lower than 25 kg/m^2 were regarded as normal weight, the subjects whose BMI was greater than or equal to 25 kg/m^2 and lower than 30 kg/m^2 were categorized to be overweight and the subjects whose BMI was greater than or equal to 30 kg/m^2 and lower than or equal to 40 kg/m^2 were considered to be obese. The AC groups classified the subjects into physically inactive, active and very active. The subjects with AC from zero to three were considered inactive, the ACs of four to six were regarded to represent active subjects and the subjects whose AC was from seven to ten were classified to be physically very active. Table 5.5 shows the number of measurement days and individuals as the measurements were grouped based on their background information.

The number of women was greater than the number of men in subjects of over 40 years, whereas the number of men was greater than the number of women in subjects under or equal to 40 years. The age group of 18–30 years old had remarkably smaller number of subjects than the other age groups. In other words, the majority of the subjects were over 30 years old and thus, the distribution of age was negatively skewed.

Overall, the distribution of BMI among the subjects was positively skewed: about 45 % of the subjects were normal weight, about 40 % were overweight and the rest 15 % were obese. However, there were some great distinctions in BMI between men and women. Over half of the female subjects were normal weight, whereas almost a half of the male subjects were overweight. Consequently, the proportion of female in the normal weight subjects is about 60 %, whereas the proportion of men in the overweight subjects is about 60 %. The difference between the number of obese men and obese women was relatively small.

The proportions of women and men were roughly the same in all AC categories. Almost 50 % of the subjects regarded their AC to be 4–6 at the scale of zero to ten. About 30 % of the subjects considered their AC to be 0–3 and almost 25 % of the subjects were athletes or otherwise physically very active i.e. their AC was 7–10.

Table 5.5. *The number and percentage of measurement days (N) and individuals (n) in the database as the subjects were grouped by their background parameters.*

Group	*ALL*		*MEN*		*WOMEN*	
	N (%)	n (%)	N (%)	n (%)	N (%)	n (%)
Age: 18–30	5 473 (10.8 %)	2 106 (11.2 %)	2 694 (11.2 %)	1 039 (11.7 %)	2 779 (10.3 %)	1 067 (10.9 %)
Age: 31–40	12 978 (25.5 %)	4 767 (25.4 %)	6 588 (27.5 %)	2 446 (27.5 %)	6 390 (23.8 %)	2 321 (23.6 %)
Age: 41–50	17 462 (34.3 %)	6 400 (34.2 %)	7 794 (32.5 %)	2 884 (32.4 %)	9 668 (36.0 %)	3 516 (35.8 %)
Age: 51–65	14 931 (14.7 %)	5 463 (14.6 %)	6 895 (14.4 %)	2 533 (14.2 %)	8 036 (15.0 %)	2 930 (14.9 %)
BMI: 18.5–25	23 361 (45.9 %)	8 567 (45.7 %)	8 855 (36.9 %)	3 277 (36.8 %)	14 506 (54.0 %)	5 290 (53.8 %)
BMI: 25–30	19 465 (38.3 %)	7 187 (38.4 %)	11 499 (48.0 %)	4 269 (48.0 %)	7 966 (29.6 %)	2 918 (29.7 %)
BMI: 30–40	8 018 (15.8 %)	2 982 (15.9 %)	3 617 (15.1 %)	1 356 (15.2 %)	4 401 (16.4 %)	1 626 (16.5 %)
AC: 0–3	14 548 (28.6 %)	5 367 (28.6 %)	6 688 (27.9 %)	2 483 (27.9 %)	7 860 (29.2 %)	2 884 (29.3 %)
AC: 4–6	24 284 (47.8 %)	8 855 (47.3 %)	10 997 (45.9 %)	4 049 (45.5 %)	13 287 (49.4 %)	4 806 (48.9 %)
AC: 7–10	12 012 (23.6 %)	4 514 (24.1 %)	6 286 (26.2 %)	2 370 (26.6 %)	5 726 (21.3 %)	2 144 (21.8 %)

The linear correlation between different background variables in men and women was studied by calculating the correlation coefficients and their p-values for background variable pairs. The correlation coefficients and their p-values are shown in Table 5.6.

Table 5.6. *The correlation coefficients between the background variable pairs. The statistically significant correlation coefficients are marked with an aster.*

	MEN		*WOMEN*	
	Age	BMI	Age	BMI
AC	0.14*	−0.23*	0.22*	−0.30*
Age	1	−0.15*	1	−0.18*

* *p-value <0.001*

The age was positively correlated with the AC in both genders. In other words, on average, the AC of the subject increased as the age of the subject increased. The BMI was negatively correlated with both AC and age. In other words, on average, an increased AC or age of the subject indicated decreased BMI.

5.3 Distribution of measurement days in years, months and weekdays

The number of measurement days varied between different years, months and weekdays. Most of the measurement days were from years 2012 and 2013 and the most popular months for measurements have been March and May. Figure 5.1 shows a detailed distribution of measurement days along years, months and weekdays.

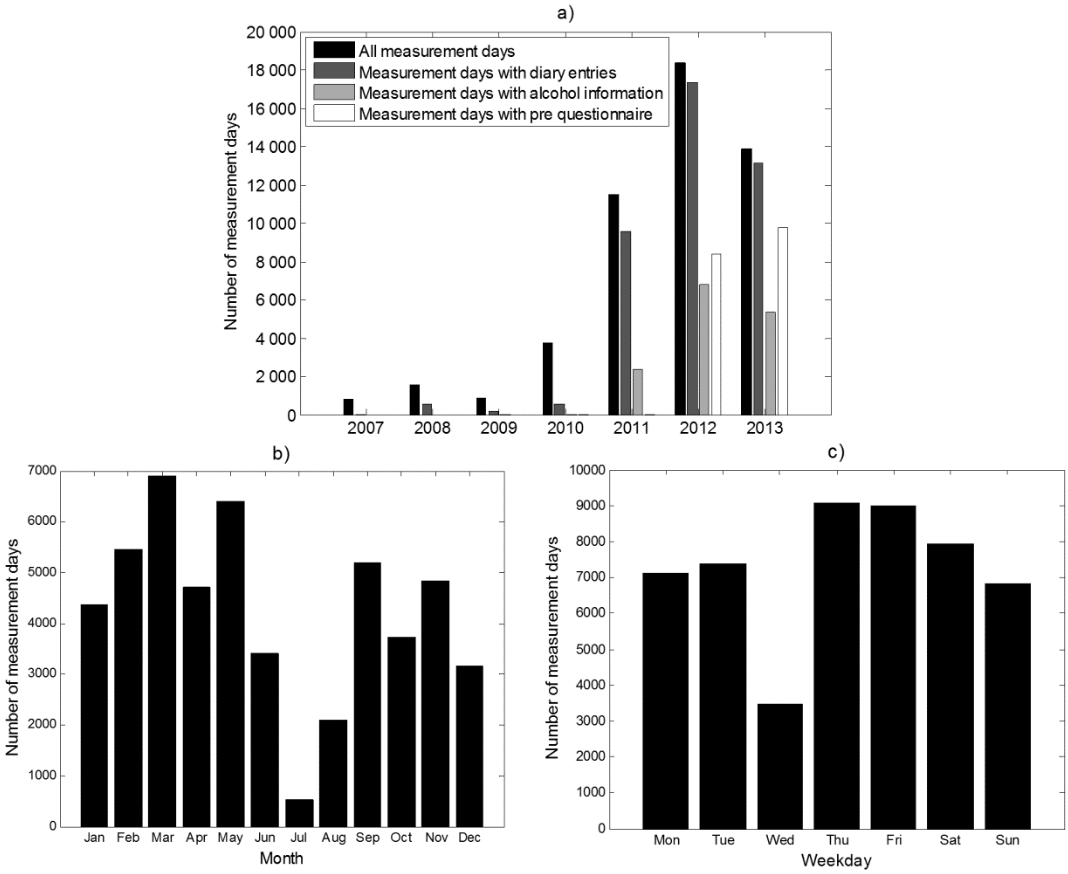


Figure 5.1. *The distribution of measurement days in years (a)), months (b)) and weekdays (c)).*

The distribution of the total number of measurement days with respect to years is shown in Figure 5.1 a). Moreover, Figure 5.1 a) shows the number of measurement days including diary entries and alcohol information in different years. The diary entries were included in almost all measurement days after year 2011. Most of the pre questionnaire answers were from years 2012 and 2013. Interestingly in years 2012 and 2013, less than half of the measurement days included information of alcohol consumption even though all the subject were asked to write down the amount of consumed alcohol during the measurement.

Figure 5.1 b) represents the distribution of measurement days along months. The number of the measurement days was lowest in July because July is the most popular holiday month in Finland. The measurement days seemed to be centered early in the year. However, year 2013 had second largest number of measurements but it included only the measurements before October since the data was collected from the servers in October 2013.

The distribution of measurement days in weekdays is shown in Figure 5.1 c). The highest numbers of measurements were performed on Thursday, Friday and Saturday whereas Wednesday had the lowest number of measurements. The distribution of the measurement days is a consequence of the Firstbeat measurement procedure since most of the people work on weekdays and the Firstbeat measurement procedure includes measuring of two working days and a day off which is typically a weekend day.

5.4 Pre questionnaire

The answers to pre questionnaire results were analyzed from subjects who had taken the measurement between years 2007 and 2013 and whose age and BMI fulfilled the inclusion criteria i.e. age was from 18 to 65 years and BMI was 18.5–40 kg/m^2. In total 6 373 subjects, who fulfilled the inclusion criteria, had answered to the pre questionnaire which considered the well-being and lifestyles of the subjects. Table 5.7 shows how the respondents were distributed into different groups according to their background parameters.

Table 5.7. *The number of respondents in different groups of subjects.*

The group of subjects	*Number of respondents (%)*
All	6 373 (100 %)
Men	3 151 (49.4 %)
Women	3 222 (50.6 %)
Age: 18–30	648 (10.2 %)
Age: 31–40	1 695 (26.6 %)
Age: 41–50	2 139 (33.6 %)
Age: 50–65	1 891 (29.7 %)
BMI: 18.5–25	3 070 (40.2 %)
BMI: 25–30	2 472 (38.8 %)
BMI: 31–40	831 (13.0 %)
AC: 0–3	1 695 (26.6 %)
AC: 4–6	3 141 (49.3 %)
AC: 7–10	1 537 (24.1 %)

Table 5.8 shows how the answers were overall distributed. The answers were separated into disagreed and agreed. The answers of ‘totally agree’ and ‘partially agree’ are regarded as agreeing the statement. Similarly, the answers of ‘totally disagreed’ and ‘partially disagreed’ are considered to disagree the statement. Table 5.8 shows the percentages of disagreed and agreed answers of all answers.

Table 5.8. *The answers to pre questionnaire statements.*

Statement	*Disagree (%)*	*Agree (%)*
1. I think I am physically active enough to get health benefits.	37.4	57.3
2. I think my physical activity is intensive enough to improve my fitness.	41.8	47.1
3. In my opinion, my eating habits are healthy.	12.2	80.7
4. I feel that my alcohol consumption is not excessive.	4.7	90.6
5. I feel stressed.	38.1	47.2
6. My days include breaks that allow me to recover.	21.5	67.4
7. I feel tired frequently.	46.8	41.8
8. I feel that I sleep enough.	34.9	55.7
9. I feel that I can influence the things that affect my health.	4.3	90.5
10. In my opinion, I feel well at the moment.	15.1	74.8

The overall well-being of the respondents was good and most of the respondents felt they can influence on their well-being. Especially, the eating and drinking habits of the respondents were healthy. In questions regarding physical activity, stress and sleep, the answers were more polarized.

Over half of the respondents said they are physically active enough to get health benefits but less than half of the respondents though the intensity of their physical activity is high enough to improve their fitness. Thus, among these respondents, the primary reason for physical activity is likely not to improve their fitness but rather to maintain it.

About 30 % of the subjects did not sleep enough and over 40 % of the subjects felt tired frequently. Thus, the tiredness of the some respondents was likely not only caused by their inadequate quantity of sleep but also by their poor quality of sleep.

Recovery is a key factor in coping with stress since the ability to recover from stress protects the body from prolonged stress. Thus, it is good that even though almost a half of the subjects felt stressed, the majority of the subjects still had in their days breaks which allow them to recover.

The effects of gender, age, BMI and AC on the pre questionnaire answers were studied by defining the correlation between the background parameters and the answers.

In order to calculate the correlation coefficients and their p-values, the pre questionnaire answers were coded as numbers according to Table 5.9.

Table 5.9. *The coding of pre questionnaire answers into numbers.*

Answer to statement	*Coded number*
‘totally disagree’	−2
‘partially disagree’	−1
‘cannot say’	0
‘partially agree’	1
‘totally agree’	2

The age, BMI and AC are continuous variables and they were used in the calculation of correlation coefficients and their p-values as such. The genders were coded so that one corresponded to a woman and two corresponded to a male. The calculated correlation coefficients and the statistical significance of their p-values are shown in Table 5.10.

Table 5.10. *The correlation coefficients between the statements and the background parameters. The statistically significant correlation coefficients are marked with an aster or asters.*

	Background parameters			
Statement number	Gender (1 = women, 2 = men)	Age	BMI	AC
1	0.034**	−0.077***	−0.280***	0.633***
2	0.084***	−0.116***	−0.182***	0.611***
3	−0.104***	0.086***	−0.245***	0.174***
4	−0.219***	−0.049***	−0.118***	0.045***
5	−0.089***	−0.085***	−0.023	−0.077***
6	−0.054***	−0.003	−0.041***	0.093***
7	−0.061***	−0.055***	0.016	−0.138***
8	−0.037*	0.039**	−0.020	0.071***
9	0.014	−0.065***	−0.067***	0.186***
10	0.071***	−0.064***	−0.142***	0.247***

** p-value <0.5, ** p-value <0.01, *** p-value <0.001*

Overall, the activity classes had the greatest correlation coefficients and the gender had the smallest correlation coefficients. In other words, the AC seemed to have the greatest impact on the pre questionnaire answers, while the gender seemed to have the smallest effect on the pre questionnaire answers. The answers of men and women were quite similar whereas the answers of the AC groups differed from one another.

The effect of AC was related to the questions considering physical activity, eating habits, sleep and overall well-being. The impact of AC was the greatest in the statements of physical activity, as presumed. The physical activity decreases as the AC decreases. Moreover, the AC influenced the eating habits: the greater the AC was, the healthier the eating habits were. The subjects, who were physically inactive, felt more frequently tired and had more often inadequate quantity of sleep than the subjects, who were physically active or very active. The overall well-being is also clearly related to the AC. In the lowest activity classes over a fifth of the subjects did not feel well whereas in the highest activity classes the correspondent percentage was lower than ten.

Questions regarding physical activity and overall well-being were also affected by age and BMI. Physical activity decreased as age or BMI increased. An increase in age or BMI also decreased the overall well-being. In addition to these, age was also related to stress but not to recovery.

The gender had the smallest effect on the pre questionnaire answers. In general, the overall well-being was better in men than in women. Men were physically more active than women. Moreover, men were more seldom tired and they had less stress than women. However, women had healthier eating habits than men.

In addition to studying the effect of background parameters on the pre questionnaire answers, also the similarity of subjects' answers to different questions was studied. Thus, the correlation coefficient and their p-values were calculated for each statement pair. The correlation coefficients and their p-values are shown in Table 5.11.

Except from the statement pair "I feel that my alcohol consumption is not excessive" and "I feel stressed", all statement pairs had statistically significant correlation. In other words, the subjects had similar answers to the questions. The highest absolute value of correlation coefficient was in the statement pair of physical activity statements. In practice, if the subject had physical activity producing health benefits, the subject's physical activity was likely to improve their fitness, as well.

Table 5.11. *The correlation coefficients between different statement pairs. The statistically not significant correlation coefficients marked with an aster*

Statement number	1	2	3	4	5	6	7	8	9	10
1	1*	0.73	0.26	0.07	–0.15	0.18	–0.20	0.17	0.23	0.37
2	0.73	1*	0.22	0.05	–0.11	0.12	–0.18	0.13	0.20	0.32
3	0.26	0.22	1*	0.18	–0.08	0.13	–0.11	0.16	0.13	0.21
4	0.07	0.05	0.18	1*	–0.02*	0.09	–0.04	0.08	0.09	0.11
5	–0.15	–0.11	–0.08	–0.02*	1*	–0.31	0.48	–0.27	–0.24	–0.43
6	0.18	0.12	0.13	0.09	–0.31	1*	–0.21	0.23	0.26	0.29
7	–0.20	–0.18	–0.11	–0.04	0.48	–0.21	1*	–0.35	–0.26	–0.47
8	0.17	0.13	0.16	0.08	–0.27	0.23	–0.35	1*	0.27	0.34
9	0.23	0.20	0.13	0.09	–0.24	0.26	–0.26	0.27	1*	0.45
10	0.37	0.32	0.21	0.11	–0.43	0.29	–0.47	0.34	0.45	1*

** p-value >0.05*

5.5 HRV parameters and HR

In this thesis, the parameters of RMSSD, LF, HF and LF/HF ratio were selected to represent HRV. Firstly, for each measurement day, which fulfilled the inclusion criteria set in Section 5.1, the average RMMSD, LF, HF and HR values were calculated based on their 10-minute averages during the measurement day. The measurement pauses were excluded from the measurement days when calculating the averages of the parameters. The average LF/HF ratio for each measurement day was calculated by dividing each sample value of LF signal by the corresponding HF signal's sample value. Table 5.12 shows the average and median values as well as standard deviations of the average parameter values in men and women. Moreover, the p-values, obtained by a Kruskal-Wallis test, are shown in Table 5.12.

Table 5.12. *The values of HRV parameters and HR in men and women and p-values for their similarities.*

	MEN		*WOMEN*		*p-value*
	Average (SD)	Median	Average (SD)	Median	
HR (bpm)	72.4 (9.0)	72.0	75.1 (8.0)	74.9	< 0.001
RMSSD (ms)	30.5 (14.4)	27.7	29.3 (13.0)	26.6	< 0.001
LF (ms^2)	2 383.4 (1 602.0)	2 031.4	1 641.8 (1 142.8)	1 356.1	< 0.001
HF (ms^2)	1 101.3 (1 092.9)	757.4	1 010.2 (937.0)	714.0	< 0.001
LF/HF	3.5 (1.7)	3.2	2.6 (1.3)	2.4	< 0.001

As shown in Table 5.12 HRV parameters as well as HR were dependent on gender. The dependency between HRV and gender was detected especially in LF values. The median value of LF in women was only about two thirds of the median value of LF in men. The higher LF value in men suggested that the sympathetic activity of ANS was greater in men than in women. On the other hand, the RMSSD and HF values indicated that men had also greater vagal activity than women. The result about the higher RMMSD in men than in women is in line with the results of Bonnemeier et al (2003) who observed that the RMSSD value is greater in men than in women in all age groups. The sympatho-vagal balance of ANS between men and women was assessed by comparing the LF/HF ratios and the LF/HF ratio was found out to be lower in women than in men.

Because of the statistically significant differences in HRV parameters and HR between the genders, the results of HRV parameters were calculated in different age, BMI and AC groups separately for men and women. These results are presented in Appendix C as tables.

The HRV parameter and HR values were statistically significantly between the age groups in both men and women. Especially, age appeared to have a great impact on RMSSD, LF and HF in both genders. As the group of 51–65 year old women was compared to the group of 18–30 years old women, RMSSD declined by over 40 %, LF declined by almost 60 % and HF declined by over 65 %. In men, the results were similar but the declines were even greater. In the group of 51–65 years old men RMMSD decreased by over 45 %, LF decreased by over 60 % and HF decreased over 70 % when compared to the group of 18–30 years old men. In other words, both the vagal and sympathetic activity decreased with age. In both genders LF/HF ratio increased with age in age groups of 18–30, 31–40 and 41–50 and the LF/HF ratio in age group of 51–65 years old was decreased when compared to the age group of 41–50 years old. As a conclusion of the results considering RMSSD and HF, the decreased HRV is correlated with increased age. This conclusion is in line with the result of Bonnemeier et al. (2003).

The results in HR, RMSSD, LF and HF values were statistically significant between both AC groups and BMI groups in men but not in women. The effects of AC and BMI on HR, RMSSD, LF and HF parameter values were opposite i.e. an increase in BMI had similar effect on RMMSD, LF and HF parameter values as a decrease in AC. RMSSD, LF and HF increased with AC and decreased with BMI, whereas HR increased with BMI and decreased with AC. The results of HR appeared to be rational as the subjects with better fitness usually have lower HR at rest.

5.6 Stress and recovery

The total amount of stress in a day was estimated by calculating the percentage of all stress reactions during a measurement day. The stress percentage of a measurement day was calculated as an average of the 10-minute stress percentages. The total amount of recovery was estimated similarly. Taking into account the diary entries, the measurement days could be separated into working days and days off. A working day was defined as a measurement day which included cumulatively at least four hours of work and a day off was defined as a measurement day which included no work at all. Furthermore, the diary entries with start and end times of the measurement period enabled calculating the amount of stress and recovery during sleeping.

5.6.1 Working days versus days off

In order to find out the impact of work on stress, the amount of stress in working days was compared to the amount of stress in days off. In the comparison of stress between working days and days off, only the subjects with both a working day and a day off, which fulfilled the inclusion criteria (defined in Section 5.1), were taken into account. If a subject had more than one working day or day off, the average of the stress percentages during working days or days off was used for comparison. The number of subjects and the stress percentages in working days and days off are presented in Table 5.13 for different groups. Moreover, the p-values for the similarity between the stress percentages within a background parameter based group between working days and days off are presented. The stress percentages were statistically significantly different between the genders, the age groups, the BMI groups and the AC groups.

Table 5.13. *The stress percentage in different groups during working days and days off. The statistically not significant differences between working days and days off within a group are marked with an aster.*

	Number of subjects	*Working day*		*Day off*	
		Mean (SD)	Median	Mean (SD)	Median
All	10 771	51.3 (13.3)	51.9	49.3 (14.2)	49.1
Men	4 778	52.5 (13.8)	53.5	50.7 (14.6)	50.6
Women	5 993	50.3 (12.8)	50.6	48.1 (13.8)	47.8
Age: 18–30	916	49.0 (12.6)*	49.5*	48.6 (14.8)*	48.2*
Age: 31–40	2 657	52.2 (12.6)	52.8	49.5 (13.8)	49.1
Age: 41–50	3 754	52.1 (13.3)	52.7	49.9 (13.9)	49.6
Age: 51–65	3 444	50.4 (13.8)	50.8	48.7 (14.7)	48.7
BMI: 18.5–25	4 851	50.1 (13.0)	50.5	48.0 (13.9)	47.7
BMI: 25–30	4 152	52.2 (13.4)	52.9	50.6 (14.3)	50.5
BMI: 30–40	1 768	52.5 (13.6)	53.3	49.9 (14.6)	50.0
AC: 0–3	3 078	53.1 (13.1)	53.8	50.4 (14.3)	50.1
AC: 4–6	5 292	51.2 (13.0)	51.7	49.4 (14.0)	49.1
AC: 7–10	2 401	49.2 (13.7)	50.0	47.7 (14.4)	47.6

** p-value > 0.05*

In all groups the average amount of stress was greater in working days than in days off. The difference between the stress levels in working days and days off was found out to be statistically significant for all groups other than the group of 18–30 year old subjects. The p-values for all groups other than the group of 18–30 year old subjects were lower than 0.001. The average amount of stress differed only by a few percent units when comparing working days and days off. Moreover, the variance in average stress percentages between different subject groups was quite small. Consequently, for an individual it might not be exceptional to have a greater stress level during a day off than during a working day. The small difference in stress levels during work and leisure has also been found out in the study of Finnish National Consumer Research Centre which suggested that stress during free time may be even greater than stress during work time (Vapaa-aika voi stressata enemmän kuin työaika 2013).

Overall, BMI and AC appeared to have opposite effects on the amount of stress. The greater the BMI was the higher was the stress percentage but the greater the activity AC was the lower was the amount of stress. The relation between the AC and stress percentage may be related to the physiological state recognition: the subject cannot physiologically be stressed and exercising at the same time. Thus, the subjects who exercise more have less time to be stressed, which may be a reason for the lowered stress percentages in physically active subjects. On the other hand, the decreased stress level in physically active subjects may support the statement that physical activity protects from stress (Hassmén et al 2000).

5.6.2 Sleep

The balance between stress and recovery during sleep was studied only among the measurement days which included the diary entry about sleeping. The analysis of sleep was performed at measurement day level as the balance between stress and recovery may vary hugely in different nights of the subject.

The balance between stress and recovery i.e. the stress balance can be defined using the Equation 5.1. The stress balance takes into account the proportions of stress and recovery during the measurement:

$$StressBalance = \frac{R-S}{R+S} \quad , \qquad \text{(Eq. 5.1)}$$

where S refers to the total time of stress during sleep and R refers to the total time of recovery during the measurement. In order to calculate the stress balance during sleep, only the part of the measurement considering sleep is taken into account. The maximum value of the stress balance is 100 and it is achieved as the sleep does not include any stress. If sleep does not include any recovery, the value of the stress balance is −100. If the amount of stress and recovery are the same during sleep, the stress balance becomes zero. The stress balance is not defined, if no stress nor recovery is detected during sleep because then the denominator becomes zero. To sum up, the stress balance can be used for assessing the quality of sleep and the greater the value of the stress balance is the more recovering the sleep is.

Table 5.14 represents the quality of sleep on average in different groups as the quality of sleep is assessed with the stress balance. The stress balance is calculated for all measurement days which included marked sleep and fulfilled the inclusion criteria (defined in Section 5.1.). The difference in stress balances were found out to be statistically significant between the genders, the age groups, the BMI groups and the AC groups (p-values <0.001 in all groups).

The overall mean of the stress balance during sleep was 40.9, which means that on average the recovery percentage during sleep was three times the stress percentage during sleep. During sleep, the stress balance was lower for women than for men i.e. men had better quality of sleep than women. In addition to gender, also other background parameters affected sleep. The differences in the quality of sleep were the greatest between different BMI groups: the greater the BMI of the subject was the poorer was the quality of sleep. The reason for diminished quality of sleep may presumably be a reason of the sleep apnea since the risk of developing sleep apnea increases, among others, with BMI (Partinen & Huovinen 2011, p. 75, 81). Also an increase in age reduced the quality of sleep. Compared to BMI and age, the AC had an opposite impact on sleep. The greater the AC was the better was the quality of sleep.

Table 5.14. *StressBalance in different groups of subject. The differences within the background parameter based groups are statistically significant.*

	Number of measurement days	*Mean (SD)*	*Median*
All	34 468	40.9 (60.1)	60.9
Men	18 527	44.2 (61.3)	68.2
Women	22 900	38.3 (59.0)	55.3
Age: 18–30	3 994	48.5 (57.9)	71.4
Age: 31–40	10 178	46.3 (58.2)	67.3
Age: 41–50	14 309	39.0 (60.1)	57.6
Age: 51–65	12 946	36.5 (61.6)	55.3
BMI: 18.5–25	18 910	47.3 (57.2)	68.3
BMI: 25–30	15 819	39.3 (61.1)	59.8
BMI: 30–40	6 698	26.7 (62.8)	40.7
AC: 0–3	11 666	32.1 (62.3)	48.8
AC: 4–6	20 192	42.0 (59.5)	62.2
AC: 7–10	9 569	49.5 (57.1)	71.9

The means and medians of stress balance values differed greatly in all groups of subjects, which was a consequence of the skewed distribution of stress balance values. The negatively skewed distribution of stress balance values is rational as normally the PNS is predominant at rest i.e. HR is decreased at rest and the decreased HR is connected with recovery in the Firstbeat's physiological state detection algorithm.

5.7 Physical activity

Physical activity was estimated by the daily total energy expenditure as well as by MET-minutes. Moreover, the MET values were used for assessing the intensity of physical activity. In other words, the estimation of the subject's physical activity is based on the information about the subject's oxygen consumption derived from measured HR data as explained in Section 3.2.

5.7.1 Daily total energy expenditure

The daily energy expenditure was calculated for all measurement days which fulfilled the inclusion criteria set in Section 5.1. The daily total energy expenditure was estimated by consumed amount of kilocalories per body weight in order to remove effect of mass on the energy expenditure. The daily energy expenditure was estimated by calculating the average of the measurement day's hourly energy expenditures. This average of hourly energy expenditures had a unit of kcals/min and thus, it was multiplied by the number of minutes a day in order to get the total energy expenditure estimation in kilocalories. The average of daily energy expenditures per body weight in men and women and the results' statistical significance are presented in Table 5.15.

Table 5.15. *The daily energy expenditure in kilocalories per body weight*

	Mean (SD) (in kcals/kg)	*Median (in kcals/kg)*
All	28.6 (8.6)	27.3
Men	30.9 (8.8)*	29.7*
Women	26.6 (7.8)*	25.3*

* *p-value <0.001*

The difference between the daily energy expenditure in men and women was statistically significant. For this reason, the energy expenditures for background parameter based groups are presented separately for men and women in Table 5.16. For both genders, the difference in results between the age groups, BMI groups and AC groups were found out to be statistically significant. The p-values for the age, BMI and AC groups in both genders were lower than 0.001.

Table 5.16. *The energy expenditure in different background parameter groups.There is a statistically significant difference in the energy expenditure between the age groups, the BMI groups and the AC groups.*

	MEN		*WOMEN*	
	Mean (SD) (in kcals/kg)	Median (in kcals/kg)	Mean (SD) (in kcals/kg)	Median (in kcals/kg)
Age: 18–30	35.7 (10.3)	34.1	34.4 (8.4)	33.7
Age: 31–40	31.8 (8.4)	30.6	29.0 (7.3)	28.2
Age: 41–50	30.3 (8.4)	29.4	26.0 (7.2)	24.8
Age: 51–65	28.7 (8.0)	27.6	22.6 (5.8)	21.5
BMI: 18.5–25	32.0 (9.4)	30.5	29.1 (8.1)	27.9
BMI: 25–30	30.5 (8.5)	29.4	24.7 (6.5)	23.6
BMI: 30–40	29.4 (8.0)	28.6	21.6 (5.7)	20.5
AC: 0–3	28.8 (7.7)	27.9	22.5 (6.0)	21.2
AC: 4–6	30.9 (8.7)	29.6	27.0 (7.2)	25.9
AC: 7–10	33.0 (9.5)	31.6	31.1 (8.7)	29.9

The energy expenditure behaved similarly with age, BMI and AC groups in both genders. The energy expenditure decreased as age or BMI of the subject increased. The result considering the decreased energy expenditure with age is in line with the results of Vaughan et al. (1991) who found out that the elderly people had decreased daily energy expenditure when compared to the younger people. Vaughan et al. (1991) concluded that the elderly had decreased energy expenditure as the elderly were physically less active than the young. The BMI was found out to be negatively correlated with the AC in Section 5.2, which presumably explains the observed decrease in energy expenditure with BMI. The increased AC indicated increased energy consumption. The observed relation between energy expenditure and AC was rational as the AC of the subject was estimated based on their physical activity and the more physically active a subject is the greater is the energy expenditure.

5.7.2 The amount of health promoting physical activity

ACSM defines that the physical activity is health promoting if it has an intensity level of greater than or equal to three METs and it takes at least ten minutes (Garber et al. 2011). Thus, the total amount of health promoting physical activity was calculated from bouts of at least 10 minutes during which the MET value was continuously greater than or equal to three. The bouts of at least 10 minutes with MET values greater than or equal to six were classified as physical activity at vigorous intensity level. The amount of physical activity at moderate intensity level was defined as the difference between the total amount of health promoting physical activity and the amount of vigorous intensity physical activity.

In the estimation of the total amount of health promoting physical activity, firstly for each measurement day the MET signal with a sampling of 30 seconds was modified to a MET signal with a sampling period of one minute by calculating the average of two consecutive MET values. From the MET signal with a sampling period of one minute, the parts of the MET signal with at least ten consecutive samples greater than or equal to three were categorized as health promoting parts of the MET signal. As the sample values of these health promoting parts of the MET signal were summed up, the total amount of health promoting physical activity in MET-minutes was achieved.

According to ACSM, the amount of physical activity is adequate to improve the cardiorespiratory fitness if the amount of physical activity is 1000 MET-minutes per week (Garber et al. 2011, p. 1338). However, already 500 MET-minutes per week has been reported to improve health and reduce the risk of CVD or premature mortality (Garber et al. 2011, p. 1338). Consequently, the amount of physical activity at moderate or vigorous intensity should be on average 150 MET-minutes per day to improve cardiorespiratory fitness.

In order to study the effect of working and leisure on the amount of health promoting physical activity, the amount of physical activity was calculated separately for working days and days off as well as for working time and free time. A measurement day including cumulatively at least four hours of work was considered as a working day whereas and a measurement day including no work was defined as a day off. As the working days were compared to the days off, only the subjects having at least a working day and a day off were taken into account. If the subject had more than one working day or day off, the average of the total amount of health promoting physical activity was calculated. The analysis of working time and free time considered only the working days and all subjects who had at least one working day were taken into account in the analysis. If the subject had more than one working day measured, the average of the health promoting physical activity amounts was used in the analysis. Moreover, the results of the amount of physical activity were analyzed separately for men and women as their amounts of physical activity were different.

Working day versus day off

In total there were 10 771 subjects who had at least one working day and one day off which fulfilled the inclusion criteria (described in Section 5.1.). For both working day and day off, the subjects were categorized into two groups: the ones not having any health promoting physical activity and the others having health promoting physical activity. The percentage of the ones not having any physical activity from all the subjects is shown in Figure 5.2 a). The average and medians values for the amount of health promoting physical activity were calculated from those having at least some health promoting physical activity. Figure 5.2 b) presents the average value and Figure 5.2 c) presents the median value for the amount of health promoting physical activity for those who had it.

The men were found out to be statistically significantly physically more active than women (p-value <0.001). However, as shown in Figure 5.2, both men and women were polarized into two groups: the ones having no health promoting physical activity and the others being, on average, physically active enough to improve their physical fitness. The polarization of the subjects considered both working days and days off but the polarization was greater in days off than in working days. In other words, the percentage of subjects having no health promoting physical activity was greater in days off than in working days but the average total amount of physical activity in subjects having health promoting physical activity was greater in days off than in working days.

The majority of men had health promoting physical activity both in working days and in days off. However, there were statistically significantly more men having health promoting physical activity in days off than in working days. There was also a statistically significant difference in the amount of health promoting physical activity between working days and days off (p-value < 0.001). However, the average amounts of physical activity during working day and day off were enough to improve physical fitness in men. The median values of the amount of physical activity indicated that in working days about a half of the subjects, who had health promoting physical activity, could improve their physical fitness while in days off clearly over a half of the subjects having health promoting physical activity could improve their cardiorespiratory fitness.

Only a minority of women had health promoting physical activity in working days or days off. The differences in the total amounts of physical activity were statistically significant in women between working days and days off (p-value < 0.001). On average the women who had health promoting physical activity had it enough to improve their physical fitness. However, the median amounts of physical activity in women indicated that in working days clearly less than half and in days of only about a half of the women could improve their cardiorespiratory fitness.

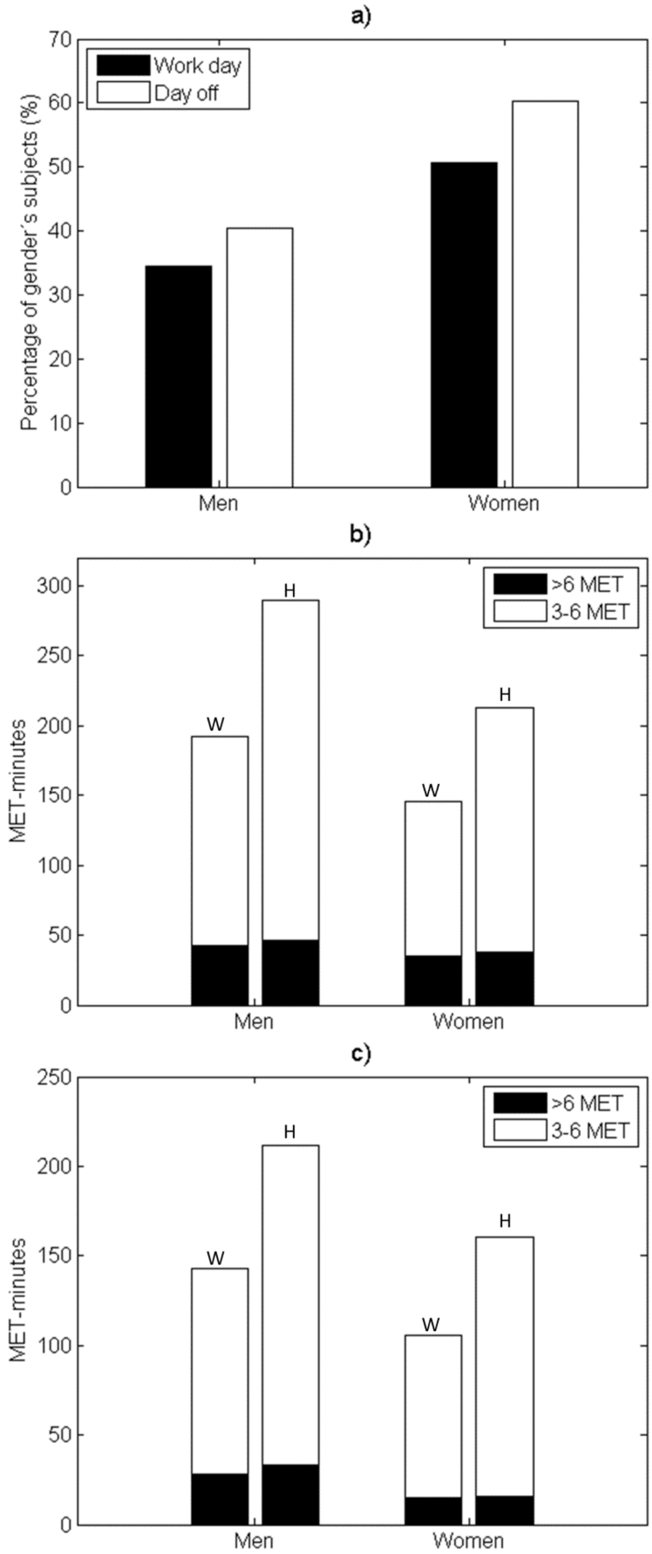


Figure 5.2. *The percentage of subjects with no health promoting physical activity is showed in a). The average (b)) and median (c)) amounts of physical activity in subjects who had at least some health promoting physical activity. In the figures, W refers to a working day and H refers to a day off. There were statistically significant differences in the participation percentages and in the amounts of health promoting physical activity between work days and days off as well as between the genders.*

The polarization of the subjects was also seen in the amount of physical activity at vigorous intensity level. Its average and median values were almost the same in both working days and days off but still statistically significantly different (p-value < 0.001). Presumably, the subjects who had physical activity at vigorous intensity level were having vigorous physical activity both in working days and days off. In other words, physically very active subjects were a separated group from the others.

As a conclusion, the subjects were polarized to the ones being physically active and the others being physically inactive. The polarization between the subjects was greater in days off than in working days. Presumably, in subjects, who had health promoting physical activity on working days but not on days off, the health promoting physical activity was a consequence of functional exercise. In working days, it is almost impossible to avoid any functional exercise, such as walking, while in days off the amount of functional exercise can be minimized if wanted.

Working time versus free time in a working day

In total there were 14 033 subjects in the database who had at least one working day which fulfilled the inclusion criteria (described in Section 5.1). The amounts of health promoting physical activity were calculated separately for working time and free time by separating the MET signals into segments considering the marked working time and free time. The effect of working time and free time on physical activity was studied similarly than the effect of working days and days off on physical activity and thus. Also the subjects were grouped similarly than when analyzing physical activity in the working days and days off. The percentage of subjects not having any health promoting physical activity was calculated and it is shown separately for men and women in Figure 5.3 a). The average and median values for the amount of health promoting physical activity were calculated from the subjects who had at least some physical activity. The average amount of health promoting physical activity is shown in Figure 5.3 b) and the median amount of health promoting physical activity is shown in Figure 5.3 c).

Nowadays, more and more people have sedentary jobs and it is seen also in Figure 5.3 a). Over 80 % of men and almost 90 % of women did not have any health promoting activity during work. The percentage of subjects who did not have any health promoting physical activity in free time was about 40 % in men and 50 % in women. The high number of subjects not having any health promoting physical activity in free time tells about sedentary lifestyle of the subjects.

The health promoting physical activity had low intensity during working, and on average, the health promoting physical activity during working was not enough to improve cardiorespiratory fitness. In free time the amount of health promoting physical activity was on average high enough to improve cardiorespiratory fitness. About half of the men and clearly less than half of the women who had health promoting physical activity in their free time had it enough to improve their cardiorespiratory fitness. The difference between the average and median amounts in women indicated that the amount of physical activity was positively skewed.

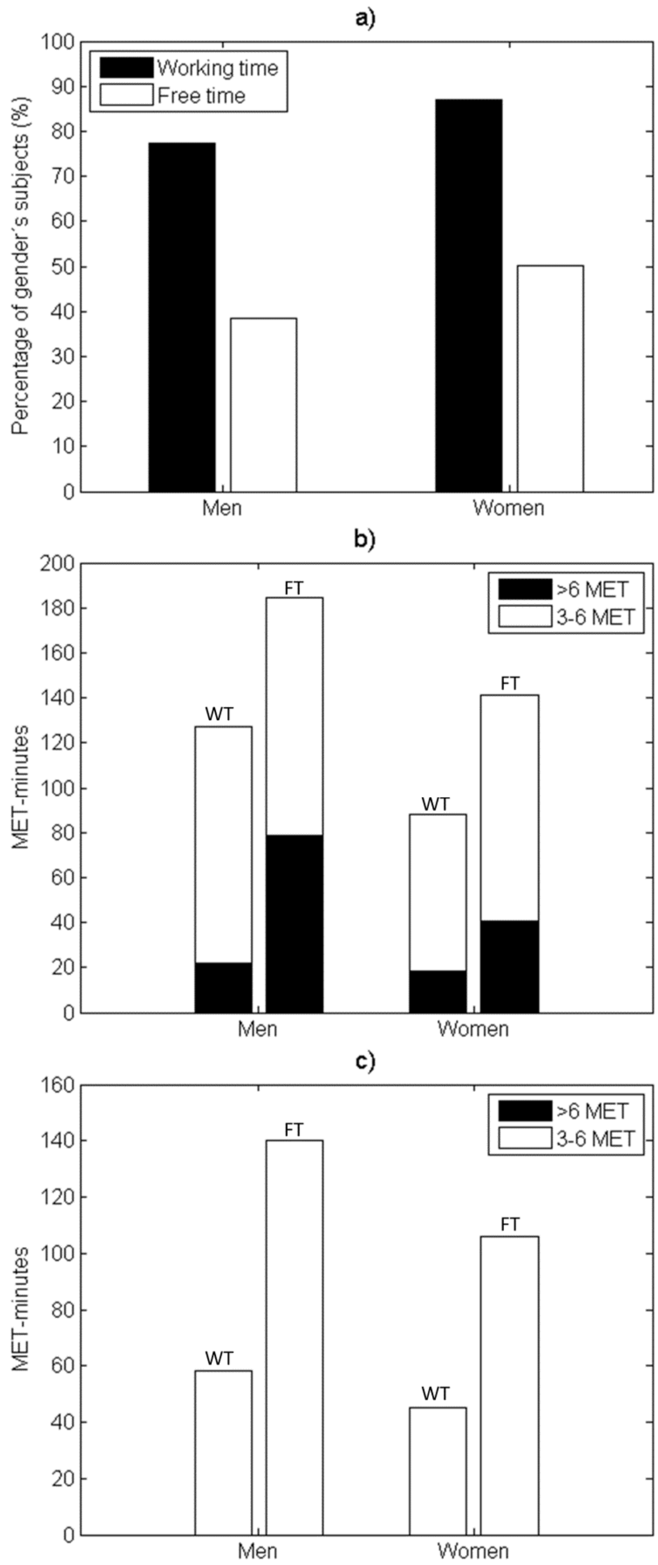


Figure 5.3. *The percentage of subjects with no health promoting physical activity showed in a). The average (b)) and median (c)) amounts of physical activity in subjects who had at least some health promoting physical activity. In figures, WT refers to working time and FT refers to free time. There were statistically significant differences in the participation percentages and in the amounts of health promoting physical activity between working time and free time as well as between the genders.*

The amount of physical activity at high intensity levels was clearly higher in free time than in working time. However, in free time the median value of the total amount of physical activity is zero in both men and women i.e. over half of the subjects had physical activity only at moderate level.

As a conclusion, most of the women did not have enough health promoting activity in their work nor free time to improve their cardiorespiratory fitness. Thus, women appeared to have more sedentary lifestyle in working days than men according to the results of this database.

5.8 The average daily profile of physiological states

The average daily profile describes how the physiological states are distributed during the measurement day. The physiological states are categorized into stress, recovery, heavy activity, light activity, exercise recovery and unrecognized. The heavy activity refers to physical activity in which the MET value is higher than or equal to 50 % of the subject's maximal MET value. Light activity refers to physical activity in which the MET value is lower than 50 % of the subject's maximal MET value. The unrecognized state considers the measurement pauses and cases in which the Firstbeat Lifestyle Assessment software has not been able to categorize the state of the body. Because the daily events in working days and days off are different, presumably also the amounts and distributions of physiological states differ.

Firstly, the measurement days with diary entries were separated into two disjoint sets: the one including all working days and the other including all measurement days without work. Thereafter, the average daily profile for a working day and a day off was calculated according to the following procedure. Firstly, the 10-minute STATE signals of the set were grouped based on the time intervals they presented. For each group the average of all the state vectors representing the same time interval was calculated and the overall average daily profile was constructed from these averages. As a result, the average daily profiles of both a working day and a day off were constructed. The average daily profile of a working day is presented in Figure 5.4 a), whereas the average daily profile of a day off is presented in Figure 5.4 b).

There was no statistically significant difference in the average daily profiles between working day and day off. The total amounts of different physiological states were quite similar during working days and days off. The total amount of heavy activity during a day off was about 11 percent points greater than the total amount of heavy activity during a working day. The differences in the total amount of other physiological states were smaller than 10 percentage points between a working day and a day off. Thus, any difference between working day and day off was related to the distribution of different physiological states during the day rather than the total amounts of physiological. Overall, all physiological states were more evenly distributed during days off than during working days but there were no statistically significant difference in the average daily profiles between a work day and a day off.

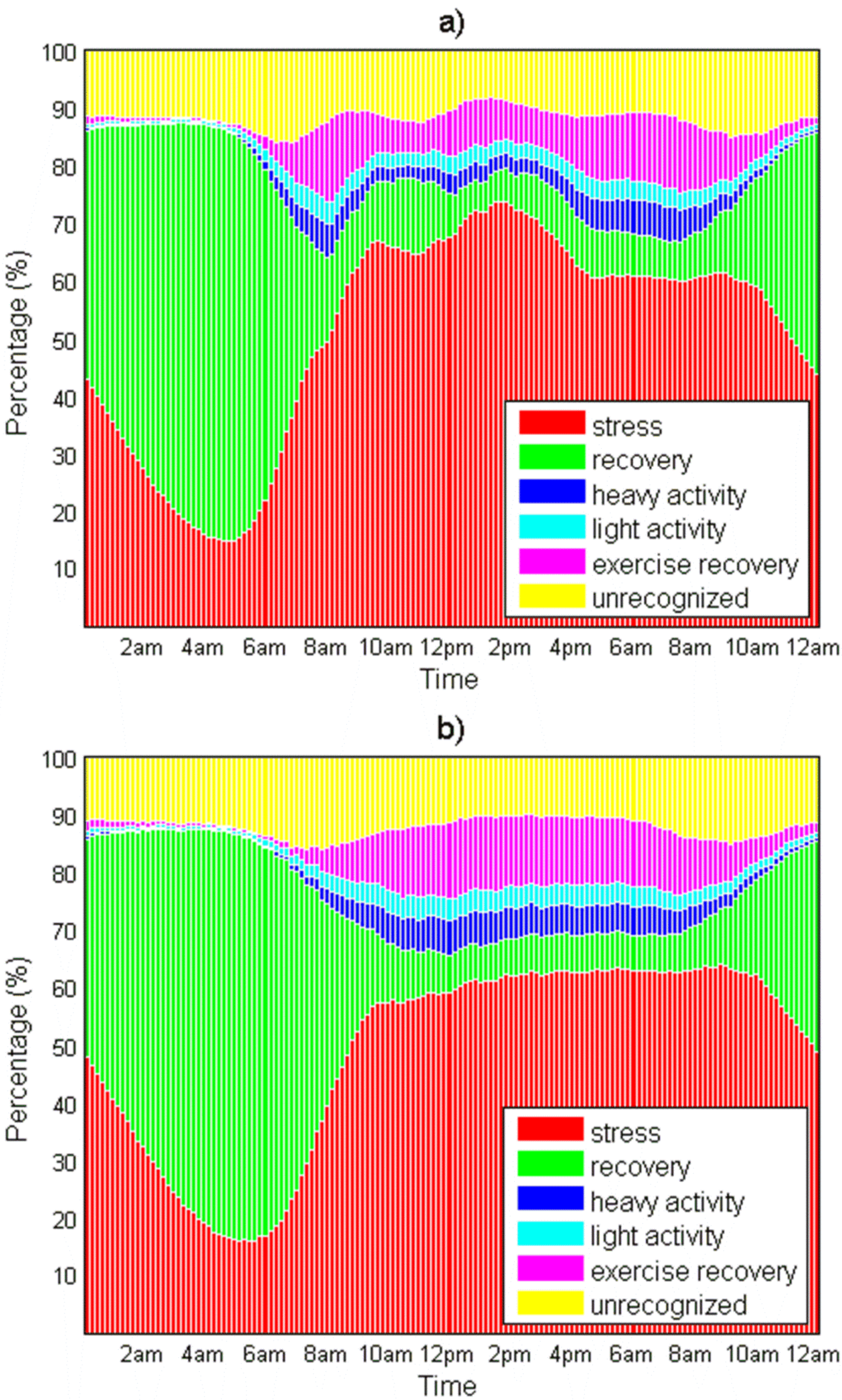


Figure 5.4. *The average daily profile of physiological states during a working day (a)) and during a day off (b)). The average daily profiles are not statistically significantly different.*

The average daily profile of physiological states, especially stress and recovery, followed the average daily rhythm of the subjects. Stress is the dominant physiological state in waking hours, while recovery is the dominant physiological state during night time. At the time of wake up the amount of stress hormone called cortisol increases rapidly in the body (Partinen & Huovinen 2011, p. 65–66), and thus, the physiological state is mainly stress during the day. On the contrary, at the time of going to sleep, the amount of stress hormone in the body has decreased (Partinen & Huovinen 2011, p. 65–66), and thus, the physiological state is mainly recovery during night.

The stress level was the lowest around 5 a.m. for both a working day and a day off. However, during a day off the lowest stress level was about 10 percentage points greater than the lowest stress level during working day. Presumably, this was a consequence of the variance in sleeping times. In other words, in days off some people stay up very late whereas the others go to sleep earlier. During a working day and a day off, the stress level increased rapidly until about 10 a.m. The stress level continued its increase until around 2 a.m. when the peak of the stress level was achieved. From to 2 p.m. until 10 p.m., the stress level remained at around constant level and in the late evening it started rapidly to decrease. During a day off, the stress level steadily and slowly increased throughout the day and around 10 p.m. the peak of stress level, which was about 10 percentage points smaller than in a working day, was achieved.

The recovery level appeared to stay at quite constant level during waking hours during both a working day and a day off. At night the recovery level increase and the peak of the recovery level was achieved around 5 a.m. In a working day the peak of the recovery level was about 10 percentage points greater than in a day off. Similarly to the increased peak stress level in a day off, this may also be a consequence of the variance in sleeping times during days off.

In a working day, the amount of physical activity was the highest in the morning before 8 a.m. and in the late afternoon from 4 p.m. until 8 p.m. The fluctuations were related especially to the physiological states of heavy physical activity and recovery from physical exercise, whereas light physical activity remained almost at constant level throughout waking hours. In a day off, all the exercise related physiological states were evenly distributed from 10 a.m. to 8 p.m.

5.9 Comparing the results of the pre questionnaire to the results of physiological measurements

The results of the pre questionnaire were compared to the results of the physiological measurements in order to find out if the subjective i.e. the pre questionnaire results and the objective i.e. the results of physiological measurement results were in line. The comparison of the subjective and objective measurement results were performed to the subjects who had answered to the pre questionnaire results and who had the corresponding objective measures. Altogether, there were 6 222 subjects who had both answered the pre questionnaire and who had at least one measurement day which fulfilled the inclusion criteria and included also sleep.

In order to compare the pre questionnaire results and the physiological measurement results, the pre questionnaire statements and their corresponding physiological measurement result were defined. For some statements a corresponding physiological measurement result could not be defined. Table 5.17 shows the pre questionnaire statements and their corresponding physiological measurement results. Also the correlation coefficients between the pre questionnaire statement results and their corresponding physiological measurement results are shown in Table 5.17.

Table 5.17. *The pre questionnaire statements and their corresponding physiological measurement results.The statistically significant correlation coefficients are marked with an aster.*

Statement in the pre questionnaire	*The corresponding physiological measurement result*	*The correlation coefficient value*
1. I think I am physically active enough to get health benefits.	the average number of minutes per day where the intensity level of the physical activity is moderate-to-vigorous for at least a 1-minute period	0.3*
2. I think my physical activity is intensive enough to improve my fitness.	the average number of minutes per day where the intensity level of the physical activity is moderate-to-vigorous for at least a 10-minute period	0.3*
5. I feel stressed.	the mean stress percentage per day	0.1*
6. My days include breaks that allow me to recover.	the mean relaxation percentage during the waking hours per day	0.1*
7. I feel tired frequently.	the mean StressBalance per night	−0.1*
8. I feel that I sleep enough.	the mean time of sleep per night	0.2*

* *p-value < 0.001*

The obtained correlation coefficient values and their p-values show that there is statistically significant correlation between the pre questionnaire results and the physiological measurement results. The results show that the subjective and objective results are in line. The greatest correlations were between the statements about the physical activity and their physiological measurement results. The positive correlation between the statements and their corresponding physiological measurement results show that people who had claimed to be physically active in the pre questionnaire really were physically active.

A bit lower correlation coefficient values were obtained for the pre questionnaire statements of stress, recovery and sleep and their physiological measurement results. The results show that those who claimed to be stressed were stressed and those who said they could recover during the day had higher recovery percentage. Similarly, the durations of sleep were positively correlated to the objective perspective on quantity of sleep. The negative correlation between the statement “I feel frequenctly tired” and the mean stress balance during sleep i.e. quality of sleep shows that those who have answered in the pre questionnaire to be frequently tired are also having poor quality of sleep.

To sum up, the objective results and with the subjective results are in line and the correlation coefficients between them are statistically significant. However, the coefficients of determination are small. The coefficients of determination are small because, in addition to the physiological measure studied, there are also other factors affecting to the pre questionnaire answers. For example, in addition to the quality of sleep, the quantity of sleep or other lifestyle related issues, which cannot be measured physiologically, may affect the tiredness as well.

6 CONCLUSIONS

In this thesis work, the Lifestyle Assessment Results data, gathered by Firstbeat Technologies Ltd of about 20 000 Finnish people in years 2000–2013, was processed into a database. The measurements are performed in real-life conditions and the Lifestyle Assessment Results data considered the background parameters of the subject, the events of the measurement days and the results of the physiological measurements which included information about the physiological state of the subject, such as physical activity, stress and recovery. In the database, the measurement results were presented as time dependent variables which were selected so that they would describe the different physiological aspects.

As a tool for simple analysis of the measurement results in the database, a graphical user interface was implemented as a part of this thesis work. The graphical user interface can be used for selecting the characteristics of the subjects and the measurement days whose measurement results are wanted to be analyzed. As the data is selected with the graphical user interface, the amount of data and some simple statistics, such as the median and mean values as well as the standard deviation, are calculated from the dataset selected by the user.

The database information was studied with descriptive statistics. In order to unify the measurement results in the database and to ensure the validity of the measurement results some inclusion criteria were set for the measurement results. The inclusion criteria considering the average artefact percentage and the duration of the measurement did not follow the recommendations. The inclusion criterion for the average artefact percentage was higher than recommended and the inclusion criterion for the duration of the measurement was shorter than recommended. However, clearle most of the measurements still achieved the recommended values and that is why, the measurement results of this database can be considered to be reliable. The measurement results which fulfilled the inclusion criteria were further used for studying correlations between the background parameters and various variables as well as studying the similarity of variable distributions in background based groups.

In this thesis, the pre questionnaire results, HRV parameters, amount of stress, quality of sleep, energy expenditure and amount of health promoting physical activity were studied with respect to the background parameters using statistical methods. The results show that most of pre questionnaire answers were statistically significantly correlated with the background parameters. The statistically significant results also show that HRV, quality of sleep and the amounts of stress and energy expenditure decrease with age. In both genders the high AC and low BMI are related to good quality of sleep, low amount of stress and high energy expenditure. In men the high AC and low BMI are also related to increase in HRV. In men the amount of stress is greater than in women but the quality of sleep is better in men than in women. Moreover, men have greater energy expenditure and more health promoting physical activity than women.

In addition to the correlations between the background parameters and various variables, the difference in the amounts of stress and physical activity as well as the daily profiles of physiological states were studied between work days and days off. The difference in the amounts of stress and physical activity differed statistically significantly between work days and days off. In days off, the amount of stress was lower and the amount of physical activity was higher than in work days. The daily profiles of physiological states were not found out to be statistically significantly different from one another.

The value of the database processed in this thesis comprises from different aspects. First of all, the measurements of the database were performed as self-monitoring in real-life conditions. Even though, the measurements are performed in real-life conditions, the some events of the measurement days are known based on the subjects' diary entries. Another advantage of the database is its size. The database includes altogether about 86 000 measurement days from about 21 500 subjects. Even though, in this thesis, the results were presented as descriptive statistics, this large database enables generating models about well-being and lifestyle related issues. The database also includes both objective measurement results as well as questionnaire results of the subjects which can be studied separately or their information can be compared.

However, the database has also some disadvantages. The measurements are performed during a long period of time and the measurements are not performed for scientific purposes. Thus, the measurement procedure has changed over the years. For instance, the pre questionnaire results are not available from the measurements conducted in the first years. This results in missing data which cannot be replaced afterwards. In the database, the subjects are also to some extent biased as most of the measurements were performed in collaboration with the occupational health care services and the measurement has been voluntary. Moreover, HRV is affected, for example, by drugs and some diseases and consequently, the measurements have not been conducted in subjects taking beta-blockers or having diabetes, for instance. Neither the medication nor the diagnosis of diseases is available in the database and that is why, the database may include some inappropriate results.

The advantages of this database are remarkable and the disadvantages of this database can be handled using a proper methodology. In future, this database can be used for various research questions which have not yet been studied. For example, the effect of alcohol on HRV parameters in a large number of subjects can be assessed with this database. To sum up, this database has a great potential to be used in scientific research about well-being and lifestyle related issues of working-age Finns in large-scale.

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APPENDIX A

FIRSTBEAT

BACKGROUND INFORMATION QUESTIONNAIRE

Measurement date ____ / ____ / _____ **Device # ____________**

Name (or ID code) _________________________

Phone number & e-mail ____

Group / Company ____

Contact person ____

Date of birth (day-month-year) ____ / ____ /_____

Gender ___ Female ___ Male

Smoking ___ No ___ Yes, over 10 cigarettes per day

Height ______cm Weight ______kg

Activity class _____ (select one number from 0 to 10 from the list on the last page)

ADDITIONAL INFORMATION (optional):

If you have had the values listed below measured during the past year, you can fill them here. However, this information is not necessary for getting reliable Firstbeat HEALTH analysis results.

Blood pressure [mmHg] __________ Blood glucose [mmol/l] ____________

Total cholesterol [mmol/l] _________ Waist circumference [cm] ________

Body fat [%] ____________ Max VO_2 [ml/kg/min] ___________

Maximal heart rate [beats/min] _____ Resting heart rate [beats/min] _____

ACTIVITY CLASS

Choose the activity class (one number between 0 and 10) that best describes your typical physical activity (endurance-type exercise or physical work) during the last 2 - 3 months:

Your typical physical activity level	Approximate weekly training amount	Activity class
I'm never physically active and I avoid all kind of physical exertion.	-	0
I'm involved in occasional light physical activity approximately once a week.	Less than 15 min	1
	Less than 30 min	2
	~ 30 min	3
I'm involved in physical activity 2-3 x per week.	~ 45 min	4
	~ 2 h	5
	2 – 4 h	6
I'm involved in physical activity 3-7 x per week.	~ 3 – 5 h	7
I'm involved in endurance-type training at least 4 x per week.	~ 5 – 7 h	7.5
I'm involved in goal-oriented endurance-type training almost daily.	~ 7 – 9 h	8
	~ 9 – 11 h	8.5
I'm involved in goal-oriented endurance-type training daily.	~ 11 – 13 h	9
	~ 13 – 15 h	9.5
	More than 15 h	10

Note! Activity classes 8-10 are meant for very fit athletes who train systematically.

APPENDIX B

FIRSTBEAT LIFESTYLE ASSESSMENT

- PRE QUESTIONNAIRE

Name

Before the Lifestyle Assessment, I would characterize my well-being and my current methods for taking care of my well-being as follows:

Questions:	Your answers:
1. I think I am physically active enough to get health benefits.	
2. I think my physical activity is intensive enough to improve my fitness.	
3. In my opinion, my eating habits are healthy.	
4. I feel that my alcohol consumption is not excessive.	
5. I feel stressed.	
6. My days include breaks that allow me to recover.	
7. I feel tired frequently.	
8. I feel that I sleep enough.	
9. I feel that I can influence the things that affect my health.	
10. In my opinion, I feel well at the moment.	

Scale of answers:

Completely agree
Partially agree
Cannot say
Partially disagree
Completely disagree

APPENDIX C

		Age: 18–30		Age: 31–40		Age: 41–50		Age: 51–65	
		Average (SD)	Median	Average (SD)	Median	Average (SD)	Median	Average (SD)	Median
HR (bpm)	Men	72.5 (9.5)	72.1	72.4 (8.7)	72.1	72.8 (9.2)	72.5	71.8 (8.9)	71.5
	Women	76.6 (8.4)	76.4	75.7 (7.7)	75.6	75.2 (7.9)	75.1	73.9 (8.1)	73.7
RMSSD (ms)	Men	43.7 (17.1)	41.2	35.6 (14.5)	33.1	27.9 (11.8)	26.0	23.4 (10.0)	21.7
	Women	40.0 (15.9)	37.4	33.9 (13.2)	31.5	27.9 (11.2)	26.0	23.7 (10.0)	21.7
LF (ms^2)	Men	3687.6 (1755.3)	3419.1	3041.4 (1609.0)	2756.1	2189.2 (1374.8)	1883.4	1464.9 (1070.0)	1184.3
	Women	2556.6 (1409.1)	2292.6	2080.6 (1167.7)	1844.2	1540.7 (998.5)	1308.0	1098.2 (804.7)	900.8
HF (ms^2)	Men	2243.7 (1628.5)	1808.4	1431.2 (1130.3)	1135.7	877.3 (766.7)	653.5	593.1 (550.3)	436.1
	Women	1854.4 (1372.0)	1479.6	1299.4 (997.8)	999.8	886.8 (756.3)	672.2	636.7 (578.7)	471.0
LF/HF	Men	2.7 (1.1)	2.5	3.3 (1.5)	3.0	3.8 (1.7)	3.5	3.6 (1.9)	3.3
	Women	2.3 (1.9)	2.1	2.5 (1.2)	2.3	2.7 (1.3)	2.5	2.7 (1.2)	2.5

statistically significant difference between the age groups in men and women (p-values < 0.001)

		AC: 0–3		*AC: 4–6*		*AC: 7–10*	
		Average (SD)	Median	Average (SD)	Median	Average (SD)	Median
HR (bpm)	Men	75.4 (8.7)*	75.2*	72.1 (8.7)*	71.7*	69.5 (8.9)*	69.1*
	Women	76.4 (8.1)	76.2	75.1 (7.9)	74.9	73.4 (8.0)	73.1
RMSSD (ms)	Men	26.2 (12.3)*	24.0*	30.1 (13.4)*	27.8*	35.7 (16.5)*	32.5*
	Women	26.3 (11.5)	24.1	29.2 (12.5)	26.7	33.7 (14.9)	30.9
LF (ms^2)	Men	1918.4 (1322.2)*	1602.0*	2371.1 (1527.5)*	2070.2*	2899.8 (1829.9)*	2522.5*
	Women	1388.1 (995.4)	1144.7	1640.7 (1107.7)	1363.2	1992.7 (1308.3)	1687.1
HF (ms2)	Men	873.7 (873.1)*	602.5*	1049.8 (975.9)*	750.9*	1433.8 (1381.3)*	980.8*
	Women	850.8 (799.3)	610.5	992.7 (891.1)	714.7	1269.6 (1139.7)	911.4
LF/HF	Men	3.5 (1.9)	3.2	3.5 (1.6)	3.2	3.4 (1.5)	3.1
	Women	2.6 (1.5)	2.4	2.6 (1.3)	2.4	2.6 (1.4)	2.3

** pvalue < 0.001*

		BMI: 18.5–25		*BMI: 25–30*		*BMI: 30–40*	
		Average (SD)	Median	Average (SD)	Median	Average (SD)	Median
HR (bpm)	Men	70.6 (8.7)*	70.2*	72.6 (8.9)*	72.3*	75.7 (9.2)*	75.3*
	Women	74.3 (8.0)	74.0	75.6 (7.9)	75.4	76.8 (8.2)	76.6
RMSSD (ms)	Men	33.4 (14.6) **	30.8**	29.8 (14.2) **	26.9**	25.7 (12.8)**	23.0**
	Women	31.5 (13.7)	28.6	27.2 (11.7)	25.0	26.0 (11.7)	23.6
LF (ms^2)	Men	2762.0 (1666.9) **	2457.7**	2302.5 (1555.1) **	1931.4**	1714.0 (1303.5) **	1382.2**
	Women	1857.3 (1238.9)	1559.2	1469.6 (988.6)	1220.0	1243.2 (884.0)	1026.1
HF (ms^2)	Men	1278.8 (1187.0) **	918.1**	1048.9 (1052.9) **	714.3**	833.5 (886.2) **	563.6**
	Women	1137.2 (1032.2)	805.7	873.1 (797.2)	632.6	839.8 (763.8)	606.2
LF/HF	Men	3.4 (1.5) **	3.1**	3.6 (1.7) **	3.3**	3.5 (2.1) **	3.2**
	Women	2.6 (1.4)	2.4	2.7 (1.2)	2.5	2.6 (1.4)	2.4

** p-value = 0.001, ** p-value < 0.001*