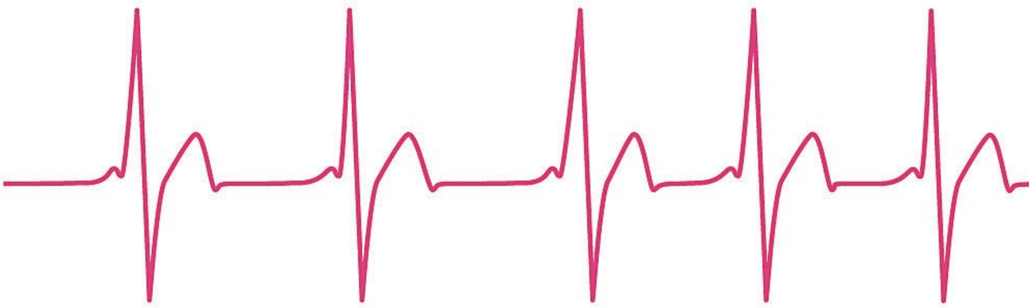
STUDIES IN SPORT, PHYSICAL EDUCATION AND HEALTH
247

Tiina Föhr

The Relationship between Leisure-time Physical Activity and Stress on Workdays with Special Reference to Heart Rate Variability Analyses



JYVÄSKYLÄN YLIOPISTO

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Esitetään Jyväskylän yliopiston liikuntatieteellisen tiedekunnan suostumuksella
julkisesti tarkastettavaksi yliopiston vanhassa juhlasalissa S212
marraskuun 4. päivänä 2016 kello 12.

Academic dissertation to be publicly discussed, by permission of
the Faculty of Sport and Health Sciences of the University of Jyväskylä,
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UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2016

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Publishing Unit, University Library of Jyväskylä

Cover illustration Tiina Föhr

URN:ISBN:978-951-39-6794-9
ISBN 978-951-39-6794-9 (PDF)

ISBN 978-951-39-6793-2 (nid.)
ISSN 0356-1070

Jyväskylä University Printing House, Jyväskylä 2016

ABSTRACT

Föhr, Tiina
The relationship between leisure-time physical activity and stress on workdays with special reference to heart rate variability analyses
Jyväskylä: University of Jyväskylä, 2016, 98 p.
(Studies in Sport, Physical Education and Health
ISSN 0356-1070; 247)
ISBN 978-951-39-6793-2 (nid.)
ISBN 978-951-39-6794-9 (PDF)
Finnish summary
Diss.

The purpose of this study was to investigate how physical activity (PA), cardiorespiratory fitness, and body composition are associated with objective heart rate variability (HRV)-based indicators of stress and recovery on workdays. Additionally, the association of subjective self-reported stress with HRV-based stress was investigated.

Samples of 81 healthy men (age 26–40 years), and 16 275 Finnish employees (6863 men and 9412 women; age 18–65 years) were assessed in the cross-sectional analyses. A sample of 221 overweight psychologically distressed individuals (36 men and 185 women; age 26–60 years) was examined in both cross-sectional and longitudinal analyses. HRV-based stress and recovery were determined from the beat-to-beat R–R interval recordings mainly over 2 workdays in a real-life setting. The Perceived Stress Scale was used to assess subjective stress. The level of PA was evaluated using both subjective (validated questionnaire/interview) and objective (real-life R-R interval recording) methods. Cardiorespiratory fitness and body fat percentage were determined under laboratory conditions. Additionally, body mass index (BMI) (kg/m^2) was used as a measure of body composition.

The results showed a positive association of subjective stress with HRV-based stress. Higher PA, cardiorespiratory fitness, and favorable body composition were associated with a lower level of HRV-based stress. Cardiorespiratory fitness and favorable body composition were associated with better recovery during sleep. A higher initial level of HRV-based stress predicted a weaker decline, whereas a higher initial level of PA and HRV-based recovery predicted a larger decline in subjective stress during a 9-month study period among psychologically distressed and overweight individuals.

The results indicate that there is an association between subjective and objective HRV-based stress measured in real-life. However, these two dimensions of stress react differently over the long term. Additionally, the results support the beneficial effects of PA on HRV-based stress.

Keywords: heart rate variability, physical activity, body composition, physiological stress, psychological stress, stress management, work stress

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ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincerest and warmest gratitude to my supervisors Professor Urho Kujala, Professor Heikki Rusko and Professor Asko Tolvanen. Thank you for your support, patience and enthusiasm for the guidance of my doctoral work. Urho Kujala had faith in me and he has guided and encouraged me throughout this research process. Heikki Rusko helped me crucially during the research process with constructive and comprehensive comments. Asko Tolvanen always had time for my questions, helping me to improve my scientific thinking and statistical skills.

I warmly thank the official reviewers of my dissertation, Adjunct Professor Arto Hautala and Dr. Marc Jarczok for sharing their knowledge as well as for their constructive comments for improving this dissertation. I am also grateful to Ina Tarkka, PhD, for her help in editing of the dissertation. I sincerely thank Professor Olli Heinonen for kindly agreeing to serve as my opponent in the public examination of my dissertation. I regard this as a great honour.

I have been fortunate to work with several co-authors during this process. I am grateful to Tero Myllymäki, MSc, Julia Pietilä, MSc, Elina Helander, PhD, Elina Järvelä-Reijonen, MSc, Katri Peuhkuri, MSc, Sanni Rantala, MSc, Riitta Korpela, PhD, Miikka Ermes, PhD, Sampsa Puttonen, PhD, Marjukka Kolehmainen, PhD, Professor Raimo Lappalainen, Harri Lindholm, MD, PhD, Sara Mutikainen, PhD, Mirva Rottensteiner, MSc, Tuija Leskinen, PhD, and Professor Jaakko Kaprio for their contribution to the original articles. I could not have managed to do the work without you. I want to thank Firstbeat Technologies Ltd. for close and rewarding collaboration. I also want to thank Ewen MacDonald, PhD, for the language revision of this dissertation.

I wish to thank the Director of the Department of Health Sciences, Professor Ari Heinonen, for providing such excellent research facilities in his department. Thank you to all the people in the Department of Health Sciences with whom I have had a pleasure to work. Special thanks to Mirva for being a close colleague and friend. I appreciate all the support and encouragement that I have received from you.

This work has been financially supported by TEKES- the Finnish Funding Agency for Technology and Innovation, Helsinki, the Juho Vainio Foundation, Helsinki, and University of Jyväskylä. I express my sincere gratitude to all these funding agencies.

During these past years I have received support from my friends – I warmly thank you all. Finally, I owe my deepest gratitude to my parents and my brothers Jussi, Hannu, and Antti for being there and supporting me. I express my most sincere thanks to my husband Tero for his love and support. I am grateful that I can share my interests, hobbies and everyday life with you.

Jyväskylä, September 2016
Tiina Föhr (nee Teisala)

FIGURES

TABLES

LIST OF ORIGINAL PUBLICATIONS

The dissertation is based on the following original publications, which are referred to in the text by their Roman numerals.

I Föhr, T., Tolvanen, A., Myllymäki, T., Järvelä-Reijonen, E., Rantala, S., Korpela, R., Peuhkuri K., Kolehmainen, M., Puttonen, S., Lappalainen, R., Rusko, H. & Kujala, U. M. Subjective stress, objective heart rate variability-based stress, and recovery on workdays among overweight and psychologically distressed individuals: a cross-sectional study. Journal of Occupational Medicine and Toxicology 2015; 10: 39. doi:10.1186/s12995-015-0081-6.

II Föhr, T., Tolvanen, A., Myllymäki, T., Järvelä-Reijonen, E., Peuhkuri, K., Rantala, S., Kolehmainen, M., Korpela, R., Lappalainen, R., Ermes, M., Puttonen, S., Rusko, H. & Kujala, U. M. Physical activity, heart rate variability–based stress and recovery, and subjective stress during a 9-month study period. Scandinavian Journal of Medicine & Science in Sports 2016; doi: 10.1111/sms.12683.

III Teisala, T., Mutikainen, S., Tolvanen, A., Rottensteiner, M., Leskinen, T., Kaprio, J., Kolehmainen, M., Rusko, H. & Kujala, U. M. Associations of physical activity, fitness, and body composition with heart rate variability–based indicators of stress and recovery on workdays: a cross-sectional study. Journal of Occupational Medicine and Toxicology 2014; 9: 16. doi:10.1186/1745-6673-9-16.

IV Föhr, T., Pietilä, J., Helander, E., Myllymäki, T., Lindholm, H., Rusko, H. & Kujala, U. M. Physical activity, body mass index and heart rate variability-based stress and recovery in 16 275 Finnish employees: a cross-sectional study. BMC Public Health 2016; 16: 701. doi: 10.1186/s12889-016-3391-4.

ABBREVIATIONS

ACTH	adrenocorticotrophic hormone
ANS	autonomic nervous system
BFH	Body & Future Health
BMI	body mass index
CFA	confirmatory factor analyses
CFI	comparative fit index
CI	confidence interval
CRH	corticotropin-releasing hormone
ECG	electrocardiogram
ERI	Effort-Reward Imbalance
FFT	FitFatTwin
HPA	hypothalamic-pituitary-adrenocortical
HR	heart rate
HRV	heart rate variability
Hz	hertz
JDC	Job Demand-Control
kcal	kilocalorie
kg	kilogram
LGM	latent growth curve modeling
m	meter
min	minute
MET	metabolic equivalent
ml	milliliter
ms	millisecond
PA	physical activity
PSS	perceived stress scale
RMSEA	root mean square error of approximation
RMSSD	root mean square of successive R-R intervals
SD	standard deviation
SAM	sympathetic-adrenal medullary
SEM	structural equation modeling
SRMR	standardized root mean square residual
TLI	Tucker Lewis index
VO_2	oxygen consumption
VO_{2max}	maximal oxygen consumption
WHO	World Health Organization

CONTENTS

1 INTRODUCTION

Sedentary lifestyle, overweight, obesity and stress are risk factors for multiple adverse health outcomes, and thus major concerns in society today. There are great efforts being expended to find ways to reduce inactivity to try to stop people becoming overweight or obese as well as avoiding stress (e.g. work-related stress). Most working age individuals spend half of their waking hours at work and so work exerts a major impact on their lives, including how much time and at what level they can enjoy daily physical activity (PA). Furthermore, the workplace may be a source of much stress and anxiety.

Physical activity (PA) confers several positive health benefits. It reduces risks for obesity and for several chronic diseases (Physical Activity Guidelines Advisory Committee 2008, Booth, Roberts & Laye 2012). Additionally, PA is an important component in the treatment of many chronic diseases (Pedersen & Saltin 2006, Kujala 2009) and it is also beneficial for mental health (Physical Activity Guidelines Advisory Committee 2008, Gerber & Pühse 2009, Suija et al. 2013). An increase in PA has been found to be associated with improved psychological wellbeing, even promoting a reduction in work-related stress (Conn et al. 2009, Thøgersen-Ntoumani et al. 2015).

Unfortunately, a substantial proportion of people do not achieve the well-known health benefits of PA due to insufficient PA (Physical Activity Guidelines Advisory Committee 2008). In global terms, approximately one third of adults do not meet the public health guidelines for recommended levels of PA (Hallal et al. 2012). This sedentary lifestyle is a major problem especially in the developed countries. Due to technological changes in these countries, PA, especially activity during working hours, has declined. Therefore, it is self-evident that leisure-time PA is increasingly important for achieving an adequate level of fitness and its associated health benefits, including mental well-being.

Most stress assessment methods primarily focus on an individual's subjective perception of stress. However, each individual's wellbeing consists of both psychological and physiological aspects (Dodge et al. 2012). In addition to how stress is subjectively perceived by an individual, stress can exert changes in several physiological processes (Cannon 1932, Cohen, Kessler & Gordon 1995) . Thus, in addition to subjective methods, stress can be measured with different objective methods. Heart rate variability (HRV) has been proposed to be a feasible method for investigating the physiological effects of stress. HRV refers to the variation in intervals between consecutive heartbeats originating from the sinus node i.e. it reflects the modulation of the autonomic control of the cardiovascular system and furthermore it can be measured non-invasively (Task Force 1996). Typically a healthy person displays high HRV with efficient autonomic mechanisms and good adaptation ability, while reduced HRV is an indicator of an abnormal and insufficiently adapted autonomic nervous system (ANS) (Porges 1992, Porges 1995, Vanderlei et al. 2009). For instance, psychological stress often causes sympathetic dominance of the ANS, and this leads to reduced HRV (Chandola, Heraclides & Kumari 2010). These physiological stress response reactions disappear during recovery; thus successful recovery after a stressful situation is a central issue in stress management (Kinnunen 2005).

The majority of previous HRV-studies have used traditional time-domain and frequency-domain measures of HRV. These parameters represent the average level of the autonomic activity over a period of the time. However, autonomic activity is very dynamic and varies during the day i.e. depending on stress, recovery and PA. Therefore, the validity of the traditional measures of HRV is limited in real-life conditions. Additionally, these measures vary extensively from individual to individual which further limits their usability in stress assessment and clinical work. However, it is also possible to determine applied heart rate (HR) and HRV-derived stress and recovery variables that take into account the dynamics and individuality of HRV and include information that is difficult to obtain from traditional measurements of HRV. One can speculate that these kinds of new objective approaches that consider the individuality of HRV could provide additional insights especially if combined with the subjective assessments of stress and its management.

The present dissertation investigated how PA, cardiorespiratory fitness, and body composition are associated with HRV-based indicators of stress and recovery during workdays. Additionally, the association of subjective stress with HRV-based stress was investigated. Furthermore, it was examined whether there is any association between PA and HRV-based stress and recovery with subjective stress over the long term. One unique aspect of the present dissertation is in the individual and dynamic method used in the assessment of physiological stress and recovery.

2 REVIEW OF THE LITERATURE

2.1 Physical activity

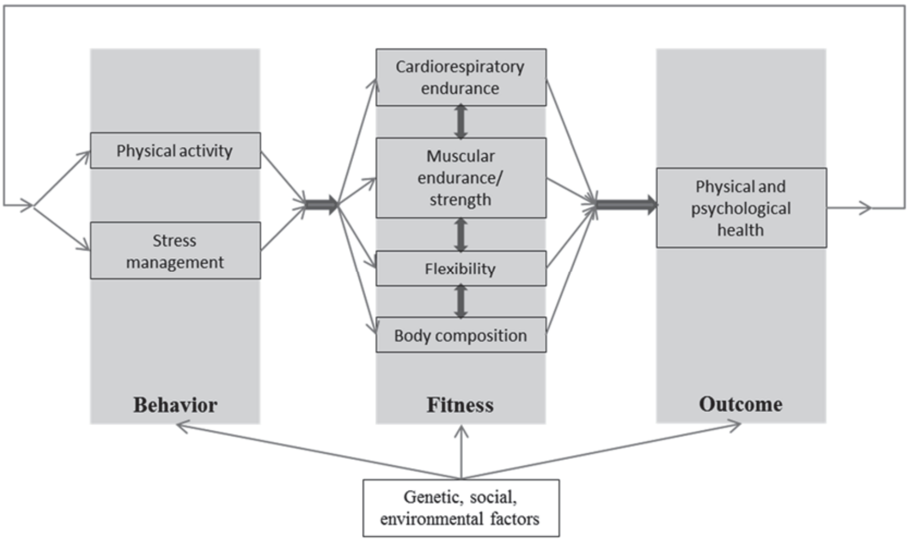
PA is defined as any bodily movement produced by the skeletal muscles that requires the expenditure of energy (Caspersen, Powell & Christenson 1985, Bouchard, Blair & Haskell 2007). Exercise is PA that is planned and structured, and involves repetitive bodily movement; its objective is to improve or maintain physical fitness (Caspersen, Powell & Christenson 1985, Tudor-Locke & Myers 2001). Physical fitness is defined as a set of attributes that people have or they achieve that is related to their ability to perform PA (Caspersen, Powell & Christenson 1985). Thus, there is a very close relationship between PA and physical fitness with PA being positively associated with physical fitness as the intensity, duration and frequency of movements increase (Caspersen, Powell & Christenson 1985, Blair, Cheng & Holder 2001). PA seems to be the principal determinant for cardiorespiratory fitness although genetic contributions to fitness are important (Blair, Cheng & Holder 2001).

2.1.1 Physical activity and health

Some PA is better than none but in order to achieve the optimal health outcomes, it is recommended that the amount of PA should be significant i.e. it should be of higher intensity, greater frequency, and/or longer duration. The general recommendations on PA for wellbeing (Physical Activity Guidelines Advisory Committee 2008, World Health Organization 2010) are that healthy adults should perform at least 150 minutes of aerobic moderate-intensity PA or at least 75 minutes of vigorous-intensity aerobic PA per week or an equivalent combination of moderate- and vigorous-intensity PA in order to achieve substantial health benefits. Aerobic PA should be performed in bouts lasting at least 10 minutes. Additionally, muscle-strengthening activities involving the major muscle groups should be done at least two times per week. In order to gain additional health benefits, it is recommended to increase moderate-intensity aerobic PA to 300 minutes per week, and vigorous –intensity aerobic PA to 150 minutes per week (Physical Activity Guidelines Advisory Committee 2008, World Health Organization 2010).

In addition to the beneficial effects of these amounts of PA for physical health, these guidelines seem to be relevant for mental health as well (Jonsdottir et al. 2010). Even though leisure-time PA has increased among Finnish adults and elsewhere around the world (Hallal et al. 2012, Helldán & Helakorpi 2015), physical inactivity is a major problem, posing a global risk for health as occupational and transport-related activity levels are declining (Hallal et al. 2012). Individuals who do not meet the recommended level of PA are often described as physically inactive (Tudor-Locke & Myers 2001). Worldwide, approximately every third adult is physically inactive and thus physical inactivity has been stated to be a contributor to the worldwide epidemic of non-communicable diseases (Hallal et al. 2012). Sedentary behavior refers to activities performed in a sitting or lying position (Pate, O'Neill & Lobelo 2008) and it is a distinct concept from physical inactivity (Tudor-Locke & Myers 2001, Sedentary Behaviour Research Network 2012). However, PA can reduce sedentary behavior.

PA exerts several positive health effects. It reduces the risks not only for obesity but also for several chronic diseases (Warburton, Nicol & Bredin 2006, Physical Activity Guidelines Advisory Committee 2008, Booth, Roberts & Laye 2012, Reiner et al. 2013). Additionally, PA is important in the treatment of many chronic diseases (Pedersen & Saltin 2006, Kujala 2009) and it is also beneficial for mental health (Physical Activity Guidelines Advisory Committee 2008, Gerber & Pühse 2009, Suija et al. 2013). Adults who are insufficiently physically active have a 20-30% higher risk of all-cause mortality compared with those who comply with the general PA recommendations (World Health Organization 2014). According to the World Health Organization (WHO), insufficient PA contributes to 3.2 million deaths and 69.3 million disability-adjusted life-years each year (World Health Organization 2014). In addition to the direct benefits of PA, there are studies indicating that the association between PA and health is mediated through physical fitness (Figure 1) (Katzmarzyk, Craig & Gauvin 2007, Sui et al. 2007). It has been claimed that the dose-response relationship between fitness and health outcomes would be higher than between PA and health outcomes. However, it is not possible to conclude whether PA or fitness is more important for health (Blair, Cheng & Holder 2001). Both PA and physical fitness are strong predictors of death (Myers et al. 2004) and furthermore they seem to exhibit a similar relationship with morbidity (Warburton, Nicol & Bredin 2006).



Health behaviors including physical activity and stress management influence several different components of fitness which in turn modulate health outcomes. Behaviors, fitness, and outcomes are influenced by genetic, social, and environmental factors. Health outcomes can also affect behaviors (modified from Blair, Cheng & Holder 2001).

FIGURE 1 Interrelationships between health behaviors, various types of fitness, and health outcomes.

2.1.2 Assessment of physical activity and fitness

PA is multidimensional and a complex behavior to measure, in fact no single assessment method can capture all the dimensions and components of PA. PA is commonly assessed as a total dose of PA consisting of the duration, intensity and frequency of PA. Duration refers to the time spent on a single bout of PA, intensity refers to the physiological effort expended in participating in a certain type of PA, and frequency of PA refers to the number of bouts of PA during a specific time period (Warren et al. 2010). PA can be subcategorized further according to different domains which are related to occupation, the routines of daily living (e.g. domestic activities, active commuting) and leisure (e.g. recreational activities, exercise and sports) (Howley 2001, Samitz, Egger & Zwahlen 2011). Thus, the assessment of PA may be focused on a specific domain. Assessment of the three dimensions (i.e. duration, intensity and frequency) of PA provides the ability to calculate the energy expenditure associated with PA. In healthy normal-weight individuals, the body oxygen consumption (VO_2) is approximately 3.5ml/kg per min at rest (Ainsworth et al. 2011). This is associated with approximately 1 kilocalorie (kcal)/kg/hour calorie cost and this is refers to 1 metabolic equivalent (MET) (Warren et al. 2010, Ainsworth et al. 2011). Other activities can be expressed as multiples of 1

MET. PA performed at two METs requires twice the resting metabolism, at three METs - three times the resting metabolism, and so on. The range 1.0–1.5 METs is considered as sedentary behavior, activities in the range of 1.6–2.9 METs are assessed as low intensity, between 3.0–5.9 MET is of moderate intensity and activities ≥ 6.0 MET are considered as vigorous intensity (Warren et al. 2010, Ainsworth et al. 2011). Instead of using absolute MET values, energy expenditure associated with aerobic PA can be expressed relative to some maximal physiological responses (i.e., maximal HR or VO_{2max}) (Howley 2001).

There are a wide variety of techniques for the assessment of PA, e.g. behavioral observation, questionnaires, and physiological markers like HR, calorimetry, and motion sensors (Westerterp 2009). Subjective assessment methods, i.e. self-report instruments are commonly used tools to assess PA. These methods include self or interviewer administered questionnaires, recalls and diaries which are inexpensive and practical ways to assess PA in a large population (Sallis & Saelens 2000, Warren et al. 2010). Despite the large-scale application, there is poor reliability and inadequate validity of the measurement of PA by self-reporting due to recall and other information biases (Westerterp 2009). For instance, both under- and over-reporting, difficulties in ascertaining the dimensions (frequency, duration and intensity) of PA, and the cognitive demands of recall are related to self-reporting (Sallis & Saelens 2000).

Technological devices and objective methods provide an alternative method for the assessment of PA. It has been proposed that one should utilize objective measures when assessing absolute amounts of PA (Sallis & Saelens 2000). Importantly, objective methods avoid some of the inherent limitations of self-report instruments, such as recall bias (Warren et al. 2010). Calorimetry, more specifically the doubly labeled water method, has become the gold standard for the validation of field methods of assessing PA (Westerterp 2009, McArdle, Katch & Katch 2010). By utilizing the known abundance of isotopes of hydrogen (^{2}H) and oxygen (^{18}O), the doubly labeled water method safely measures the average metabolic rate of an organism over a period of time in free-living conditions (Melanson, Freedson & Blair 1996, Westerterp 2009). However, the doubly labeled water method is too costly and laborious to be considered applicable for large-scale studies (Melanson, Freedson & Blair 1996). Nevertheless, it is used as the standard method against which other PA assessment methods are validated (Melanson, Freedson & Blair 1996, Westerterp 2009, McArdle, Katch & Katch 2010). Motion sensors, such as accelerometers and pedometers, and HR monitors are often used to assess PA as they are relatively inexpensive, easy to wear, and they can be used in free-living conditions (Westerterp 2009). Pedometer and accelerometer methods are based on registering body movement and measuring the acceleration of the body in one or several planes (Tudor-Locke & Myers 2001). However, the inability to measure all activities limits the usability of these measures (Warren et al. 2010). Furthermore, accurate methods of monitoring PA that capture cardiorespiratory loading are needed. HR monitoring is a commonly used method to assess the intensity of PA in a clinical setting (Westerterp 2009) and it has also been used in a free-living setting to assess the daily amount of moderate to vigorous PA (e.g. Mutikainen et al. 2014). HR is almost linearly associated with VO_2 at moderate to submaximal intensities while the subject performs steady-state exercise. Nevertheless, the relationship between HR and VO_2 is curvilinear for very low intensity activities and also when near maximal exercise. To avoid the problems of assessing low activity intensities, HR monitoring method should only be used to measure the time spent in moderate and vigorous PA (Warren et al. 2010).

The close relationship and differences between PA and physical fitness have been described earlier. In addition to the above mentioned differences, an important distinction between PA and fitness is the intra-individual day-to-day variability in PA, whereas fitness is a relatively stable concept. The assessment of maximal oxygen consumption (VO_{2max}) provides information about the cardiovascular component of fitness. A variety of exercise tests that activate the body's large muscle groups can be used to determine VO_{2max}. The direct measurement of VO_{2max} in which the subjects are required to exercise to exhaustion is considered to be the most accurate method to assess an individual's level of cardiovascular fitness. In most cases, the test consists of progressive increments in effort expended on a treadmill or cycle ergometer (McArdle, Katch & Katch 2010). However, this direct test is costly and time consuming and it is difficult to motivate certain, e.g. overweight, individuals to undertake exhausting exercise. Therefore, submaximal exercise test protocols that predict VO_{2max} have been developed (Fitchett 1985). These tests require less equipment, time and are easily administered since they do not need to be performed by highly skilled personnel. The most popular methods of sub-maximal exercise testing have been those which predict VO_{2max} by extrapolation from the relationship of sub-maximal VO_2 and HR values to an assumed age-related maximal HR (Fitchett 1985). A sub-maximal exercise test has been shown to be a valid method in the assessment of VO_{2max} (Arena et al. 2007).

In summary, the assessment of PA is challenging. Both subjective and objective methods have their advantages and disadvantages. Measurement method may have a significant impact on the determined levels of PA. Self-reported levels of PA have been found to be both higher and lower than objectively measured levels of PA. The existing literature reveals that there is a need for valid, accurate and reliable ways of measuring PA e.g. for assessing current and changing PA levels, as this could help clarify the relationships between PA and health outcomes (Prince et al. 2008).

2.2 Body composition

Unfortunately, not only is physical inactivity a major concern in today's society, but it is accompanied by the common incidence of overweight. It is likely that the current epidemic of obesity is caused largely by changes in the physical environment that favour physical inactivity (Philipson & Posner 2003). It is well known that obesity is associated with adverse health consequences i.e. it is a major cause of many diseases, including type 2 diabetes mellitus and cardiovascular disease (Bray 2004), and death (Pischon et al. 2008). Thus, many countries have set national targets to combat the high prevalence and consequences of overweight and obesity and often one way to achieve these goals is to encourage their citizens to undertake PA (Branca, Nikogosian & Lobstein 2007, World Health Organization 2014).

2.2.1 Assessment of body composition

Obesity has been defined as a process of excess fat accumulation due to a chronic positive shift of the energy equation, resulting from an increase in energy input, a decrease in energy output, or both (Solovieva et al. 2013). According to the WHO, in 2014 a significant proportion, 39%, of the world's adults were overweight, and 13% were obese (World Health Organization 2014). Different parameters have been used in the assessment of body composition but perhaps the most commonly used measure of overweight and obesity is body mass index (BMI) which is defined as a person's weight in kilograms divided by the square of height in meters (kg/m^2). According to the definition devised by WHO, BMI between 18.5 and 24.9 is determined to be normal or healthy weight, BMI greater than or equal to 25 is overweight, and BMI greater than or equal to 30 is obesity. These BMI ranges are valid for Western countries (World Health Organization 2014). BMI provides a useful population-level measure of overweight and obesity. However, there are some limitations to BMI, i.e. it is acknowledged that it may not correspond to the same degree of fatness in different individuals as it is not a direct measure of body fat. Nevertheless, BMI is considered to be a convenient and reliable measure of obesity (Garrow & Webster 1985). In addition to BMI, body fat percentage has been used as an index of adiposity. The upper limit of normal body fat percentage is 20% for men and 30% for women. Obesity is considered to exist along a continuum from the upper limit of normal to a value as high as 50% as well as to a theoretical maximum of nearly 70% of body mass in the extremely obese (McArdle, Katch & Katch 2010). In addition to BMI and body fat percentage, waist circumference and waist-hip-ratio are used as measures of obesity. The cutoff points for waist circumference of 102 cm in men and 88 cm in women and cutoff points for waist-to-hip ratio of 1.0 in men and 0.85 in women have been proposed to define abdominal obesity and to identify persons at higher risk for developing certain diseases (Pischon et al. 2008).

2.2.2 Physical activity and obesity

PA, a major life style factor, has traditionally been one of the main targets in preventing and treating obesity. PA increases energy expenditure and may prevent weight gain. There are studies suggesting that PA plays an important role in the prevention of body fat accumulation (Waller et al. 2010, Kujala et al. 2013, Reiner et al. 2013). For instance, DiPietro et al. (2004) noted that the daily

PA level was negatively associated with weight gain among 2 501 healthy male adults during a five year follow-up time. Those individuals who maintained the same level of PA did not gain weight, while those individuals who reduced their daily PA level suffered a considerable increase in their body weight (Di Pietro, Dziura & Blair 2004). Furthermore, DiPietro et al. (2004) reported that those individuals who increased their PA level during the follow-up experienced a weight loss. Individuals who do not put back on the weight lost over time have been found to undertake more PA than their counterparts who regained the lost weight (Weinsier et al. 2002). In addition to the long term benefits of PA, some studies have detected a cross-sectional relationship between overweight and physical inactivity as higher BMI has been found to be associated with lower PA (Hansen et al. 2013, Mutikainen et al. 2014).

In summary, there is a consensus that there is a negative association between PA and weight gain (Reiner et al. 2013). Regular PA is a key determinant of energy expenditure and is therefore fundamental to energy balance, weight control and prevention of obesity (World Health Organization 2014). However, the causality of this relationship is not clear; i.e. is physical inactivity a contributor to obesity or vice versa nor is it clear to what extent the association is causal (Bauman et al. 2012, Reiner et al. 2013). Obesity is a complex condition with many causal contributors, such as many behavioral factors in addition to PA, socioeconomic, environmental, and genetic factors (Qi & Cho 2008).

2.3 Stress

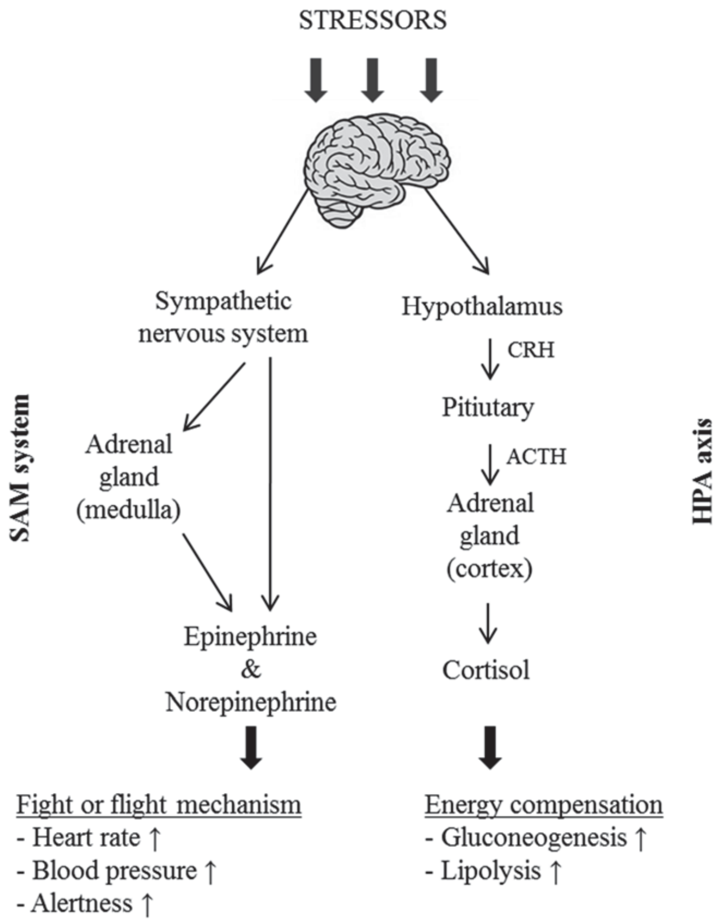
Stress has been defined by a number of authors in many different ways, focusing on its sources, consequences and/or resources to overcome the negative stress effects. The way in which the term "stress" has been used in the literature has been inconsistent and there is confusion about the meaning and measurement of stress (Cohen, Kessler & Gordon 1995). Hans Selye, a pioneer in the area of stress research, was the first scientist who introduced the concept of stress. He described stress as a general, non-specific physiological response to any stressor. Later, he extended this concept by drawing attention to the difference between eustress (good stress) and distress (bad stress) (Abbas, Farah & Apkinar-Sposito 2013). However, the physiological stress responses to both of these forms of stress are similar. The Transactional Model of Stress and Coping by Lazarus & Folkman (1984) provides a framework for evaluating the processes of coping with stressful events. Stressful experiences are interpreted as transactions between the person and his/her environment. These transactions depend on the impact of the external stressor. This is firstly mediated by the person's appraisal of the stressor and secondly by the social and cultural resources at his or her disposal (Lazarus & Folkman 1984). Thus, what one person experiences as stress is not the same as that felt by another person and this may therefore result in different physiological patterns.

2.3.1 Physiological stress responses

The physiological stress responses include changes in the function of ANS and hormonal systems. The function of ANS is modulated by its parasympathetic and sympathetic components (Malliani et al. 1991). The physiological symptoms of acute stress are commonly associated with the sympathetic dominance of ANS function (Cannon 1932). However, the heart is under a tonic inhibitory control by parasympathetic influences. This is supported by the evidence showing that when both cardiac vagal (the primary parasympathetic nerve) and sympathetic inputs are blocked pharmacologically, the individual's intrinsic HR is higher than his or her normal resting HR (Jose & Collison 1970).

The sympathetic-adrenal medullary (SAM) system and the hypothalamic-pituitary-adrenocortical (HPA) axis are two interrelated pathways that are viewed as the primary indicators of stress (Cohen, Kessler & Gordon 1995). The stress responses mediated by these two systems are presented in Figure 2. The SAM system reacts to psychosocial stressors with increased secretion of two hormones, epinephrine and norepinephrine. The SAM system's response to a stressor includes elevated blood pressure, increased HR, profuse sweating, and constriction of peripheral blood vessels. Vagal hypoactivity is associated with the perception of threat and it is thought to complement the fight or flight mechanism induced by the SAM system (Thayer et al. 2012). In the modern world, the relevance of "fight or flight" might not be very suitable in everyday life. Instead, the regulation of appropriate adaptive processes to stress is primarily mediated by vagal activity (Porges 1995) as also evidenced by vagal and sympathetic blockade study during the standing up test (Martinmäki et al. 2006a). Similarly, at low exercise intensities, an increase in HR results from vagal withdrawal and from both vagal withdrawal and sympathetic excitation at moderate and high intensities (Robinson et al. 1966, Orizio et al. 1998). The HPA system triggers the initial reactions necessary to confront the demands made by the stressor. The anterior pituitary gland secretes adrenocorticotrophic hormone (ACTH), which in turn activates the adrenal cortex to secrete cortical hormones (primarily cortisol in human beings) to adapt to the stressor. If the stressor is sufficiently severe and prolonged, the anterior pituitary and the adrenal cortex lose their capacity to secrete hormones, the adaptation to the stressor can no longer occur and the symptoms reappear (Cohen, Kessler & Gordon 1995).

Genetic and environmental conditions modulate these regulatory mechanisms (Xiong & Zhang 2013). In addition to the hormones of the SAM and HPA, changes in the secretions of other hormones, neurotransmitters, and brain substances have been found to be associated with the stress response (Cohen, Kessler & Gordon 1995).



Stressors, including social, psychological and biological factors activate the stress system. Brain activates (i) the sympathetic-adrenal medullary system (SAM) and the fight or flight mechanism, and (ii) the hypothalamic–pituitary–adrenal (HPA) axis that stimulates cortisol release from the adrenal cortex and thereby mobilizes energy as stress compensation. CRH, corticotropin-releasing hormone; ACTH, adrenocorticotrophic hormone. (Modified from De Vriendt, Moreno & De Henauw 2009).

FIGURE 2 The stress system.

2.3.2 Theories of stress

According to various several stress models and theories, stress is considered as a process which includes both the psychological and physiological attributes of the individual and the surrounding environment and where this unity is affected by a stress factor, i.e. stressor. If an individual perceives this stressor as a threat, its presence will produce negative emotional, behavioral and physiological responses which eventually may lead to different health problems and diseases. As described above, the ANS and HPA axes are important pathways leading to positive adaptation to stress but over longer time intervals, they can cause negative health consequences. The Allostatic Load Theory suggests that the adaptive physiological mechanisms of the human body are affected if the physiological balance becomes disturbed (McEwen 2000). The allostatic load consists of the function of neuroendocrine, immune, metabolic and cardiovascular systems. In the normal allostatic response, a response is initiated by a stressor, sustained for an appropriate interval, and then turned off. The adverse effects of continued adaptation process without recovery induce an excessive allostatic load which may be termed an allostatic burden, if this load is very high or frequent (McEwen 2000). Thus, recovery from stress is a crucial part of stress management. An incomplete recovery is associated with adverse health consequences and it is even a risk factor for cardiovascular diseases (Kivimäki et al. 2006).

In general terms, recovery is described as a process that develops when the stressors imposed on the individual are no longer present. An individual's functioning returns back to its pre-stressor level, strain is reduced during the recovery process (Meijman & Mulder 1998) and the individual is capable and ready to continue with his or her current demands, or to confront new demands (Zijlstra & Sonnentag 2006). The Effort-Recovery Theory suggests that an unavoidable stress associated with working triggers load reactions such as physiological activation. However, under optimal conditions, once the individual is no longer exposed to the work stress, these load reactions are reversed and recovery occurs. Thus, work stress should not pose long term negative health consequences as long as individuals recover sufficiently after work (Meijman & Mulder 1998). If prolonged exposure to work load leads to continuous physiological activation, the extent of the recovery has been inadequate. This insufficient recovery may be traced to an employee having to perform new tasks at work while still in a strained state and thus the need for recovery increases further (Meijman & Mulder 1998). According to Effort-Recovery Theory, one important aspect of recovery is that the previously mentioned functional systems; neuroendocrine, immune, metabolic and cardiovascular systems, activated during work are no longer strained. However, if an individual is unable to detach from work and is thinking about work-related issues during leisure-time, the functional systems are still challenged and complete recovery cannot occur (Sonnentag & Fritz 2007). It has been suggested that prolonged activation of the functional systems is an important mediating mechanism through which the work load leads to illnesses. Therefore, it is crucial that there are effective processes to curtail this prolonged activation in order to return an individual's function to its pre-stressor level (Sonnentag & Fritz 2007).

There are also several stress theories which focus on the psychological aspects of stress. The psychological aspect of stress emphasizes the subject's perception and evaluation of the potential harm caused by the stressor. An individual's perception of stress arises when the demands encountered are perceived to exceed his or her ability to cope with those demands (Cohen, Kessler & Gordon 1995). One of the best known theories is Karasek's two-dimensional (1979) Job Demand-Control (JDC) model which proposes that individuals who concurrently experience high psychological demands (e.g. high workload) and low decision/control latitude at work are more likely to develop health problems. A newer stress model, the Effort-Reward Imbalance (ERI: Siegrist, 1996) model suggests that employees experiencing an imbalance between effort and reward at work are at risk of developing stress and stress-related diseases (Siegrist 1996).

Work-related stress can be confused with some closely related concepts, such as occupational burnout. Occupational burnout can develop as a result of chronic stress caused by job demands exceeding an employee's resources for managing his or her work tasks. However, burnout has been clearly distinguished, both conceptually and empirically, from other forms of stress (Cordes & Dougherty 1993). It comprises three dimensions; overwhelming exhaustion, cynicism toward work and people related to it (depersonalization), and feelings that one's work has no value (reduced personal accomplishment) (Maslach, Schaufeli & Leiter 2001, Näätänen & Kiuru 2003). Job stress differs from occupational burnout in particular with regard two of the dimensions of burnout. The exhaustion component represents the basic individual stress dimension of burnout and refers to feelings of being overextended and depleted of one's emotional and physical resources (Maslach, Schaufeli & Leiter 2001). In addition, the depersonalization component of burnout refers to the interpersonal context dimension of burnout, the component of reduced personal accomplishment represents the self-evaluation dimension of burnout (Maslach, Schaufeli & Leiter 2001). These two dimensions constitute attitudinal components of burnout which are not covered by the traditional concept of stress (Cordes & Dougherty 1993).

2.3.3 Measurement of stress

Many researchers have been interested to find ways to assess stress and both subjective and objective instruments for the measuring of stress have been developed. Stress, e.g. at work, can be assessed by utilizing questionnaires that are based on the earlier described theories of stress, JDC and ERI. In addition to this theory-based operationalization of stress at work, a large number of studies have examined workplace stress according to the definition of the different aspects of stress, e.g. the Perceived Stress Scale (PSS) (Cohen, Kamarck & Mermelstein 1983) which includes stress-related items such as being subjected to time pressure and having interpersonal conflicts. Some of the stress assessment methods have focused on subjective and direct measures related to work, whereas others have concentrated on general measures which do not include dimensions related to work. Additionally, some subjective methods are based on assessing symptoms of stress such as depression, anxiety and burnout.

However, due to the problems related to subjective measures which are based on individual's subjective perception of stress, it has been recommended that objective measures of stress should be preferred. More sophisticated physiological measures of stress such as cardiovascular variables and stress hormones can be used and these measures can be considered as being more accurate. One common hormonal measure of stress is circulating or excreted corticosteroids which are produced and secreted by the adrenal cortex during and after exposure to a stressor. Their release is one part of the activation of the HPA system presented earlier (Figure 1). Cortisol is the primary human glucocorticoid; its release displays a clear diurnal rhythm. The peak in the cortisol level takes place in the morning after which it declines slowly throughout the day. Cortisol can be measured from plasma, urine, and saliva (Cohen, Kessler & Gordon 1995). However, using stress hormones as measures of stress involves complex laboratory processes whereas HRV has been suggested to be a more practical method of stress assessment. In addition to the assessment of stress from ANS activity, HRV analyses have recently attracted remarkable interest in the assessment of recovery from daily load during the night.

2.4 Heart rate variability

HRV refers to the beat-to-beat (R–R interval) temporal variation in between the consecutive heart beats originating from the sinoatrial node and detected as the normal sinus rhythm in an electrocardiogram (ECG) recording (Figure 3). HRV is modulated by both components of the ANS, i.e. its parasympathetic and sympathetic arms (Malliani et al. 1991). HRV has gained importance as a technique to explore the sympatho-vagal balance of the ANS, which has an important role in maintaining homeostasis. Normally, sympathetic activation of the ANS increases after exposure to different inherent and environmental stressors; these elevate HR and decrease HRV. In contrast, under restful conditions there is an attenuation of sympathetic activity, and a dominance of parasympathetic activity, resulting in a decrease in HR and an increase in HRV (Montano et al. 2009, Vanderlei et al. 2009).

FIGURE 3 Heart rate variability.

HRV has become a popular clinical and investigational tool (Billman 2011). The roots of the HRV research lie in the 18th century. Stephen Hales (1733) was the first to report the association between respiration, HR and blood pressure. He observed an increase in HR during inspiration and a decrease in HR during expiration (Hales 1733). This phenomenon of beat-to-beat fluctuation of HR is known as respiratory sinus arrhythmia. The first recordings of respiratory sinus arrhythmia were introduced in 1847 by Carl Ludwig. With the measurement of the ECG (1895) and the appearance of the portable ECG recorder in the 1960s, analysis of HRV developed rapidly and today there is much interest in clarifying the relationship between HRV and its health and disease (Billman 2011).

In general terms, a higher HRV characterizes a healthy person with efficient autonomic mechanisms and good adaptation abilities whereas reduced HRV is an indicator of abnormal and insufficient adaptation of the ANS (McMillan 2002, Vanderlei et al. 2009). With respect to work stress (Thayer, Yamamoto & Brosschot 2010), a great variety of cardiovascular risk factors and both cardiovascular and non-cardiovascular diseases have been shown to reduce HRV, e.g. obesity (Skrapari et al. 2007), smoking (Karakaya et al. 2007), hypertension (Maule et al. 2008), diabetes (Rosengård-Bärlund et al. 2009), and heart failure (De Jong & Randall 2005). Additionally, it has been recognized that HRV decreases with age (Umetani et al. 1998, Zulfiqar et al. 2010) and heritable factors may explain a substantial proportion of the variation present in HRV (Singh et al. 1999).

Computer-based techniques make it possible to analyze R-R intervals in different domains and there are now a great number of indices of HRV in existence (Task Force 1996). Time domain and frequency domain are the primary approaches applied in the analysis of HRV (Task Force 1996, Denver, Reed & Porges 2007). Of those two, the time domain measures of HRV are easier to calculate but tend to provide less detailed information than their frequency domain counterparts. One of the most common spectral analysis approaches is the fast Fourier transform method (Task Force 1996, Denver, Reed & Porges 2007). Traditional time-domain and frequency-domain measures of HRV represent the average level of the autonomic activity over a period of the time. However, autonomic activity is very dynamic and varies during the day depending on stress, recovery and PA. In addition to these linear time-domain and frequency-domain measures of HRV which are not able to describe accurately changes in beat-to-beat HR dynamics, non-linear methods have been used to quantify the dynamics of HR fluctuations (e.g. Tulppo et al. 1996). These more complex non-linear analyses of HR dynamics are being widely evaluated. For instance, in patients who have experienced a previous myocardial infarction, the non-linear analysis can reveal abnormal patterns in the R-R interval behavior that are not easily detected with linear methods (Mäkikallio et al. 1996).

Published HRV-studies have mainly used traditional time-domain and frequency-domain measures of HRV, such as root mean square of successive R-R intervals (RMSSD) and the ratio of low frequency power to high frequency power. As described, the traditional measures of HRV represent the average level of the autonomic activity over a period of the time. HRV displays a circadian pattern with the highest values occurring during night sleep followed by a decline after awakening (Furlan et al. 1990). Furthermore, cardiac autonomic activity is very dynamic and varies during the day, depending on stress, recovery and PA. Additionally, other factors e.g. age, diseases like hypertension and diabetes, ethnicity, medication, smoking, alcohol and caffeine consumption, and breathing are potential confounders in HRV studies (Task Force 1996; Jarczok et al., 2013). Therefore, the usability of the traditional measures of HRV, which are feasible in laboratory settings, is limited in real-life conditions. Additionally, these measures are very individual which further limits their applications in stress assessment and clinical work. However, nowadays it is possible to provide applied HR and HRV-derived stress and recovery variables that take into account the dynamic changes in autonomic activity and individuality of HRV including information that is difficult to obtain from traditional measures of HRV. These novel variables take into account many factors such as HRV-derived respiratory variables and individual resting HR and HRV values (Firstbeat Technologies Ltd. 2014). Due to very high inter- and intra-individuality of HRV (Martinmäki et al. 2006b), these kinds of new approaches which take into account both the individuality in HRV and the great variety in the autonomic control could provide additional insights into the usability of HRV in practical situations by enabling a feasible measurement of HRV-based stress and recovery in real-life settings.

2.5 Association of subjective stress with heart rate variability-based stress

Most stress assessment methods primarily focus on an individual's subjective perception of stress. However, psychological stress causes sympathetic responses in ANS, such as reduced HRV (Montano et al. 2009). Several studies have detected an association between higher psychological stress and lower HRV (Jarczok et al. 2013, Tonello et al. 2014). The association between work stress and HRV components indicates that work stress leads to vagal withdrawal and sympathetic activation reflecting a sympathetic dominance of the ANS (Malik & Camm 1993). However, it is challenging to compare the published studies investigating the association between subjective self-reported stress and HRV since they have applied different methods with a wide range of different questionnaires for the assessment of (work) stress as well as different measures of HRV. However, most of the previous studies have used traditional time- or frequency-domain measures of HRV which represent the average level of the autonomic activity over a period of the time, not taking into account the diurnal variation in HRV. Furthermore, the comparison between the studies is complicated since the duration of the HRV measurement period between the studies has varied greatly, from a few minutes to over 24 hours.

Most of the previous studies have utilized cross-sectional study settings providing no information about the causality of the relationships. For instance, Clays et al. (Clays et al. 2011) reported an association of traditional HRV measures derived from 24-hour recording with self-reported work stress assessed by Job Stress Questionnaire. Their results were similar after adjustment for several health behaviors including PA (Clays et al. 2011). The findings of Clays et al. (2011) who examined 653 healthy male workers support the concept that in particular, the parasympathetic component of the ANS is related to work stress. This idea is further supported by the findings of Collins and Karasek (2010) who examined 36 healthy males including 6 times 5 min periods during the 48-h monitoring; they found reductions in variance of cardiac vagal activity in high job strain subjects, with further reductions in subjects reporting exhaustion (Collins & Karasek 2010). In a previous study, Collins et al. (2005) used the same data and found similar results. They included the whole HRV recording period for a total of 48 hours from the start of one workday with the next day being a day off work. Hanson et al. (Hanson et al. 2001) used the ERI to assess work stress of 70 individuals including both men and women. They found that a higher need for control was associated with lower HRV. Loerbroks et al. (2010) also applied the ERI in their assessment of work stress. Their study group consisted of 591 employees, including both men and women, and HRV was recorded over 24 hours. The authors concluded that the association of work stress and HRV appeared to be most pronounced in employees aged 35-44 (Loerbroks et al. 2010). In addition, some studies with relatively small sample sizes, have found job stress to be related to a reduced HRV as extracted from ≥ 24-h ECG monitoring (Vrijkotte, van Doornen & de Geus 2000, Van Amelsvoort et al. 2000, Uusitalo et al. 2011).

The evidence for the association between subjective and HRV-based stress derived from longitudinal studies is scarce, with the results being somewhat inconsistent. Eller et al. (2011) utilized a longitudinal setting and they recorded HRV for approximately 18 hours but examined only 3 times 5 minutes segments (the participant was sitting) of the HRV data in their analysis. In agreement with the previously presented result, they detected a cross-sectional association between an adverse psychosocial work environment as assessed by the ERI and a low HRV. Nevertheless, no statistical significance was found between the HRV estimated in 2006 with the ERI evaluated in 2008 (Eller et al. 2011). In the study of Pärkkä et al. (Pärkkä et al. 2009), an intervention which involved lectures about stress management and exercise exerted a positive effect on participants' subjective stress levels. However, the study did not report significant changes in HRV-based stress or recovery between the pre- and post-intervention times. Melville et al. (Melville et al. 2012) found that 15 minutes of yoga and meditation were associated with reduced subjective stress and positive changes in HRV-based stress. The change in subjective stress was maintained at 15-min post-intervention. In contrast, Cheema et al. (Cheema et al. 2013) found that although a 10-week yoga intervention exerted a positive change on participants' self-reported anxiety, it did not result in any improvements in their HRV profiles.

In addition to the studies described above, the association of HRV with subjective self-reported stress has been examined by utilizing short term HRV recordings conducted in laboratory conditions (e.g. Chandola et al. 2008). Chandola et al. (2008) found HRV to be associated with self-reported work stress. The authors claimed that this was a direct effect of work stress on HRV, as adjusting for health behaviors did not change the observed association (Chandola et al. 2008). Additionally, there are several reports using laboratory simulations which detected reduced HRV as a short term response to acute mental stress while the subjects performed standardized tasks (Steptoe et al. 2002, Hall et al. 2004, Isowa, Ohira & Murashima 2006).

In addition to studies investigating the relationship between HRV and work stress, the association of HRV with self-reported health has been evaluated. Self-rated health is associated with many indicators of both physical and mental health, such as work stress (Pinquart 2001, Schmidt et al. 2014, Jarczok et al. 2015). For instance, Jarczok et al. (2015) examined 3947 working adults and found poorer self-rated health to be associated with lower HRV as well as with higher work stress. The authors concluded that the extent of brain–body communication, as indexed by HRV, was associated with self-rated health (Jarczok et al. 2015).

2.6 Association of physical activity with stress

PA has been shown to benefit both mental and physical health. PA has been associated with a reduced incidence of reported mental health problems (Goodwin 2003, Ströhle et al. 2007). In addition, it has been postulated that individuals who exercise regularly have a lower risk for developing stress-related mental health disorders than their inactive counterparts (Gerber & Pühse 2009). An increase in PA has been found to be associated with improved psychological wellbeing, including decreased job stress (Conn et al. 2009, Thøgersen-Ntoumani et al. 2015). It is believed that high stress levels can attenuate an individual's willingness or ability to engage in regular exercise and to be physically active (Sonnentag & Jelden 2009). However, Carson et al. (2010) found evidence that PA could act as a buffer against emotional exhaustion rather than PA being decreased as a consequence of exhaustion. Rimmele et al. (2009) studied the beneficial effect of PA on both subjective self-reported and objectively measured physiological stress. They found that elite male athletes reported less state anxiety to psychosocial stress (i.e., public speaking) together with significantly lower cortisol and HR levels compared to their untrained male counterparts. Nonetheless, the measurement method of PA may have an impact on the association of PA with mental health including stress. For instance, Hamer and Stamakis (2010) reported that objectively assessed moderate to vigorous PA was not associated with psychological health even though there was an association between self-reported PA and psychological health.

There are several mechanisms potentially involved in the relationship between PA and stress. PA may confer protective effects on mental health by increasing resilience to stress via enhanced regulation of the stress response, as shown in both self-report (Hegberg & Tone 2015) and by assessment of physiological parameters (Forcier et al. 2006). The positive effects of PA are explained by the association of increased PA and fitness with enhanced physiological stress regulation. The regulation of cardiovascular activity is commonly identified as a marker of physiological resilience to stress. The Cross Stressor Adaptation Theory provides a theoretical framework for understanding the protective effects of PA (Salmon 2001). This theory postulates that regular PA and good fitness lead to adaptations in how an individual responds to both exercise and psychological stressors as the stress of regular PA induces biological changes that augment the body's response to PA and other physiological stressors (Salmon 2001, Forcier et al. 2006). For instance, PA and fitness have been found to predict well-regulated cardiovascular activity in studies conducted in laboratory settings investigating the physiological responses to mental stressors (Forcier et al. 2006). Repeated bouts of exercise lead to physiological adaptations, including decreases in resting HR and blood pressure and increases in parasympathetic activity (Tulppo et al. 2003). There may be other mechanisms involved in the association of PA with stress as postulated by the endorphin and thermogenic-related hypothesis. The improved mood after exercise has been suggested to be a consequence of elevated levels of endorphins (Grossman et al. 1984). However, the evidence concerning this theory is inadequate and it has been questioned by a number of investigators (e.g. Schwarz & Kindermann 1992, Ekkekakis & Petruzzello 1999). The thermogenic hypothesis of exercise postulates that increased body temperature is responsible for subjectively increased mood following exercise (Raglin & Morgan 1985). In summary, the association of PA with stress could be explained through several biological processes (Hamer 2012).

It has been suggested that during stressful periods, PA results in reduced subjective stress response and healthier behavior. For example, the psychological explanations for the benefits of PA are that engaging in PA helps to detach from daily stressors, such as work, and further leads to an improved mood during and after PA (Morgan 1985). Additionally, the benefits of PA have been explained in such a way that PA provides a sense of mastery via conquered challenges and feelings of competency as the individual learns and masters a new skill (Throne et al. 2000) and the ability to be regularly involved in this activity may lead to improved mood and self-confidence (North, McCullagh & Tran 1990). Detachment from work and a sense of mastery together with the sense of control which can also be achieved by leisure-time PA, are important factors for recovery, both during the day and while sleeping (Sonnentag & Fritz 2007). Additionally, social interactions and mutual support in connection with PA are factors which are considered as important for mental health (Morgan 1985).

2.7 Association of body composition with stress

The link between obesity and stress has been explained in various ways. Both direct and indirect effects of stress on obesity are proposed as explanatory mechanisms for the association of stress with obesity. Firstly, stress may increase the risk of weight gain and obesity directly via hyper-activation of the HPA axis with its resulting metabolic changes (Fig. 2) (Rosmond 2005, Brotman, Golden & Wittstein 2007, Foss & Dyrstad 2011). Secondly, stress may increase the risk of weight gain and obesity indirectly through behavioral factors, such as leisure-time physical inactivity (Kirk & Rhodes 2011).

Obesity has been found to be associated with altered ANS activity (Gao et al. 1996, Karason et al. 1999) and HRV profiles seem to be relatively poor among obese subjects (Zahorska-Markiewicz et al. 1993, Karason et al. 1999, Kim et al. 2005, Millis et al. 2010) but they can be improved after weight loss (Karason et al. 1999, Rissanen, Franssila-Kallunki & Rissanen 2001). It is interesting to note that each of the obesity associated risk factors for heart disease and stroke; high blood pressure (hypertension), diabetes, and elevated cholesterol levels have been found to be associated with decreased HRV (Thayer et al. 2010). Additionally, a higher BMI has been found to be associated with higher concentrations of C-reactive protein, an inflammatory marker (Visser et al. 1999). Furthermore, it has been postulated that there would be an inverse association between HRV and plasma levels of C-reactive protein (Thayer & Fischer 2009). The results of a recent study by Jarczok et al. (2016) indicated that the association between higher work stress and poorer glycemic status was partially mediated through HRV and that it was independent of systemic inflammation as measured by C-reactive protein. The findings of Karason et al. (1999) suggested that obese individuals have increased sympathetic activity and a withdrawal of vagal activity and that these autonomic disturbances improve after weight loss with a 1 year follow-up. Obese subjects treated with surgery had a mean weight loss of 32 kg, whereas body weight remained stubbornly stable in the group of obese subjects only treated with dietary recommendations (Karason et al. 1999). Additionally, Millis et al. (2010) found a negative correlation between body fat percentage and HRV in a small sample of male university students. Grassi et al. (2004) noted that sympathetic activity among normotensive adults was greater in obese subjects than in lean controls. Additionally, they found that the increase in sympathetic activity was greater in individuals with an abdominal or central distribution of body fat in comparison with those who had more peripheral fat depot (Grassi et al. 2004). In line with the findings of Grassi et al. (2004), Gao et al. (1996) also found worse HRV profiles in women with upper-body obesity rather than lower-body obesity and with visceral rather than subcutaneous obesity. Furthermore, an association of sympatho-vagal balance with BMI has been observed in healthy, non-obese individuals (Molfino et al. 2009, Koenig et al. 2014).

In addition to these negative physiological health effects of obesity, the association of obesity/overweight with psychological stress has been extensively evaluated. Normal weight is claimed to be associated with good self-reported subjective health (Asztalos et al. 2013) including stress-coping skills (Nyberg et al. 2012, Proper et al. 2012). For instance, Nyberg et al. (2012) found that both obesity and being underweight were associated with high levels of work-related stress (Nyberg et al. 2012), independent of sex. Additionally, employees of normal weight have reported the lowest prevalence of emotional exhaustion and chronic psychological complaints compared with their underweight, overweight and obese colleagues (Proper et al. 2012). However, according to previous studies, the association between subjective stress and body composition has been inconsistent i.e. there is evidence both supporting (Block et al. 2009, Nyberg et al. 2012) and refuting this link (Overgaard, Gyntelberg & Heitmann 2004, Armon et al. 2008). A recent systematic review reported that the associations of psychosocial factors at work with weight-related outcomes were weak and somewhat inconsistent (Solovieva et al. 2013). It was concluded that differences in study design, heterogeneity of the methods applied to assess work stress or weight status, and confounding factors included in the analyses may account for the contradictory findings or weak associations (Solovieva et al. 2013).

3 AIM OF THE STUDY

The present study aimed to investigate how PA, cardiorespiratory fitness, and body composition are associated with objective HRV-based indicators of stress and recovery on workdays. Secondary goal was to examine the association of subjective self-reported stress symptoms with HRV-based stress and recovery. Furthermore, the association between PA and HRV-based stress and recovery with subjective stress in the long term was investigated. The specific aims were:

1. To investigate the cross-sectional associations between subjective stress and HRV-based indicators of stress and recovery on workdays among overweight and psychologically distressed individuals by taking into account PA level and body composition (Study I).

2. To investigate the effects of PA and HRV-based stress and recovery on subjective stress among overweight and psychologically distressed individuals over a 9-month study period (Study II).

3. To investigate how PA, cardiorespiratory fitness, and body composition are associated with HRV-based indicators of stress and recovery on workdays among male participants with different PA levels (Study III).

4. To investigate the amount and intensity of HRV-based stress and recovery on workdays among a real-life sample of 16 275 Finnish employees by taking into account their PA level and body composition (Study IV).

4 PARTICIPANTS AND METHODS

4.1 Study designs and populations

The present study utilized several data sets some of which were originally collected to primarily answer research questions other than those of the present dissertation. The working-aged participants in each study of this dissertation are presented in Figure 4.

Study I and II The cross-sectional (Study I) and longitudinal (Study II) studies involved 221 individuals (36 men and 185 women; age 26-60) with different occupations with symptoms of metabolic syndrome and psychological distress who met the inclusion criteria in the initial screening for a controlled, randomized trial (Elixir study) published previously (Lappalainen et al. 2014). The participants were randomly allocated into one of three low intensity psychological intervention groups (internet-based, mobile-technology based, or face-to-face) as well as one control group. The internet-based intervention comprised a web-guided intervention including coaching methods and health assessment. The mobile-technology based intervention consisted of mobile-guided mindfulness, acceptance and value-based exercises which were similar to the face-to-face intervention. The face-to-face intervention involved six group sessions supervised by a psychologist. The participants randomized into the control group did not participate in active intervention but they participated in all the measurements. These interventions have been described in detail previously (Lappalainen et al. 2014). Data collection for the study was done at three time points; baseline, 10 weeks' post-intervention, and at the 36-week follow-up. Data for Study I consisted of the baseline measurements. Data from all the three time points of data collection was utilized in Study II. The inclusion criteria were self-reported BMI 27–34.9 kg/m^2, and perceived elevated psychological stress as indicated by a score of at least 3/12 points on the General Health Questionnaire (Makowska et al. 2002). The participants did not have any severe chronic illnesses, and any regularly taken medications and changes in medication during the study period were reported. Individuals who used α- or β-adrenergic blocking agents affecting the heart were excluded from the analysis. However, other regular medication was allowed.

Study III The cross-sectional study investigated 81 healthy males (age 26–40 years). The population of this study was made up from two separate studies, the FitFatTwin study (FFT study) and the Body & Future Health study (BFH study). The identical measurements of the cross-sectional FFT study and the baseline measurements of the BHF were pooled for the analysis. The final study population included both inactive and active individuals as the FFT study was enriched with pairs having within-pair differences in their PA habits. The inclusion criteria for the BFH study were: BMI 25.0–35.0 kg/m^2, waist circumference ≥94 cm, no vigorous exercise (>20 min/session) more than twice a week, and no smoking. Thus, the participants from the FFT study had on average a more favorable body composition, better cardiorespiratory fitness, and a higher self-rated activity class. Individuals who were not on regular medication were included in the study.

Study IV The participants of the cross-sectional study were 16 275 Finnish employees (6 863 men and 9 412 women; age 18-65 years). The majority of the participants were apparently healthy and they had participated in preventive occupational health care programs provided by their employers during the years 2007-2015. The participants non-selectively represent a cross-section of typical Finnish employees including both manual and non-manual laborers. The majority of the participants were apparently healthy without chronic diseases. The exclusion criteria for participation in the R-R interval recordings included severe cardiac disease, very high blood pressure (≥180/100 mm Hg), type 1 or 2 diabetes with autonomic neuropathy, severe neurological disease, fever or other acute disease, and BMI >40 kg/m^2. Individuals who had consumed alcohol during the beat-to-beat R-R interval recording were excluded from the analysis.

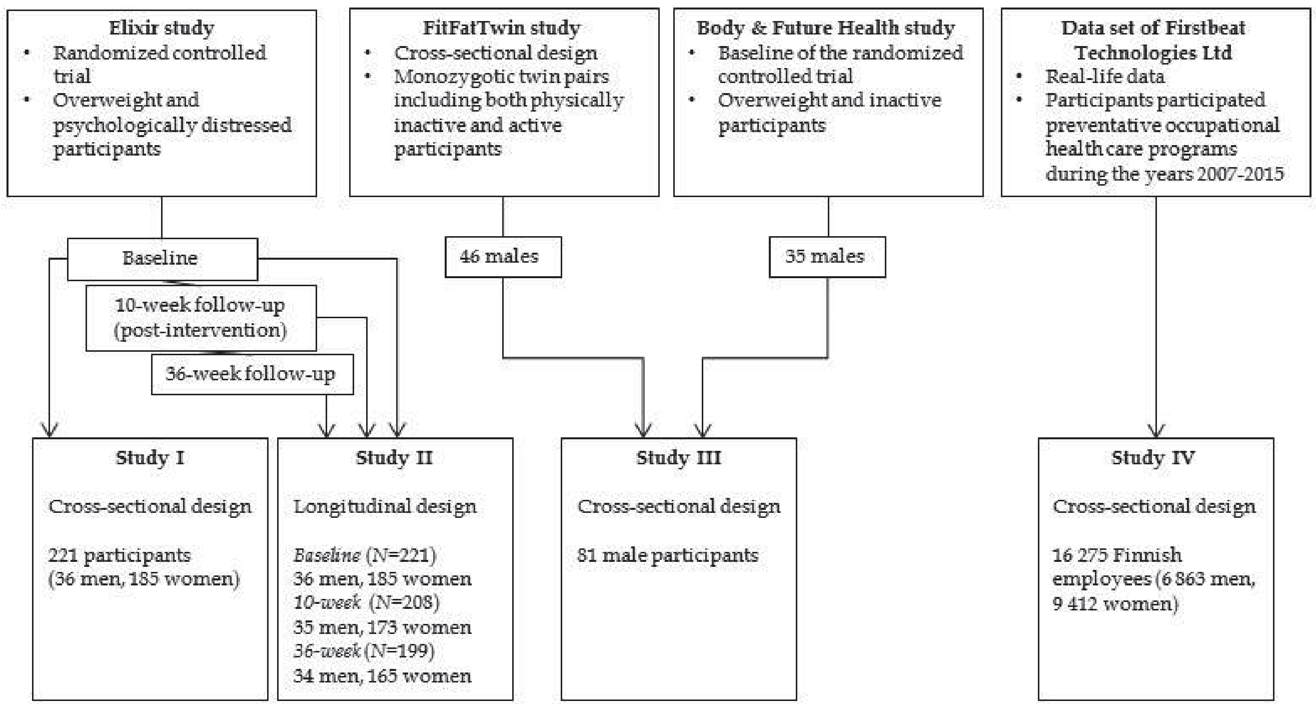


FIGURE 4 Participants in the studies of the dissertation.

4.2 Assessment of physical activity and fitness

4.2.1 Subjective assessment of physical activity (Studies I, II, III)

The volume of PA (MET index) was assessed using a validated questionnaire with items regarding present activity and changes within the last two months (Kujala et al. 1998, Waller, Kaprio & Kujala 2007). The structured questions covered both leisure-time and commuting PA and were related to the intensity, duration and frequency of PA. A slightly different version of the questionnaire was used in Studies I and II (Appendix 1) compared to Study III (Appendix 2). In Studies I and II, the assessment of PA was accomplished as a self-administered questionnaire whereas in Study III, the assessment of PA was made during an interview. A MET was assigned for each activity to describe the intensity of the form of PA. The MET indices for each form of PA were calculated by multiplying the intensity (MET), duration (h), and monthly frequency of the activity, and the MET index (MET-h/d) was expressed as the sum score of different activities.

4.2.2 Objective assessment of physical activity (Study IV)

The assessment of the level of PA was based on the R-R interval recordings in Study IV (see a more detailed description of the analysis of the R-R interval data in chapter 4.3.1 Objective heart rate variability-based stress). From the second-by-second VO_2 estimations, the subject's mean VO_2 for each minute of the measurement day was calculated (Mutikainen et al. 2014). Thereafter minute-by-minute VO_2 estimations were converted to METs by dividing the VO_2 values by 3.5. The total number of 1-minute segments within the following thresholds: 3 to < 6 METs (moderate PA) and ≥ 6 METs (vigorous PA) during each measurement day (including days off work) was calculated. The bouts of PA lasting continuously for ≥ 10 minutes were included in the estimation of the amount of weekly PA. These calculations were performed separately for workdays and days off work and if the measurement period included two or more workdays or days off, an average was calculated. The activity minutes score for each day (moderate PA minutes + vigorous PA minutes x 2) was calculated. Thereafter, the amount of PA was extrapolated using the following formula: PA minutes per week = (5 x mean workday activity score) + (2 x mean day off activity score). The calculations have been described in more detail previously (Mutikainen et al. 2014). Based on the weekly PA minutes, the participants were divided into the following PA groups according to the 2008 Physical Activity Guidelines Advisory Committee (Physical Activity Guidelines Advisory Committee 2008): inactive (0 min), low (>0 - <150 min), medium (150–300 min) and high (>300 min) PA level (Study IV).

4.2.3 Cardiorespiratory fitness (Study III)

In Study III, cardiorespiratory fitness was assessed using the cycle ergometer test and a slightly modified WHO protocol (Andersen et al. 1971) with 2-min stages and 25 W/stage increases in workload. The test was submaximal in the BHF study, whereas in the FFT study it was maximal and included a breath-by-breath respiratory gas-exchange analysis. The submaximal cycle ergometer test was ended after the workload during which the tested person achieved the submaximal HR level (85–88% from the maximal HR), which was defined from maximal HR based on the participant's age (210 – (0.65 × age)). In the analyses, the values used for the VO_{2max} are the results of submaximal workload-based calculations for all participants.

4.3 Assessment of stress

4.3.1 Objective heart rate variability-based stress (Studies I, II, III, IV)

Objective HRV-based stress and recovery on workdays were determined from the beat-to-beat R–R interval recordings in real-life settings using a Firstbeat Bodyguard measurement device (Firstbeat Technologies Ltd., Jyväskylä, Finland). The recording frequency (i.e. sampling rate) of the device was 1000 Hz. The recordings were undertaken mainly over 3 days including two workdays and one day off work.

The recorded data were then analyzed using the Firstbeat Analysis Server software (version 5.3.0.4 in Studies I-III, version 6.3 in Study IV). Based on the person's age, gender, height, weight and self-reported PA class, the method estimated the person's maximal HR, maximal respiration rate, and VO_{2max}. The individual range of the physiological variables, e.g. resting HR and maximal HR were automatically updated from the recorded R-R-interval data if lower or higher values, respectively, were observed. The software included an automatic artifact detection and correction feature for irregular ectopic beats, and excessive signal noise (Saalasti et al. 2004). The original R-R interval series were resampled at a rate of 5 Hz by using linear interpolation to obtain equidistantly sampled time series, and second-by-second HRV indices reflecting the activities of the sympathetic and parasympathetic nervous systems were calculated with the short-time Fourier transform method by using constant duration Hanning filter window (Saalasti 2003, Martinmäki et al. 2006b). The software categorized the data into different physiological states such as stress, recovery, and the PA of different intensities by taking into account individual characteristics (e.g. individual levels and scales of HR and HRV, and the individual relationships between HRV and autonomic control) (Martinmäki et al. 2006b). Stress was detected when sympathetic activity of the ANS dominated over parasympathetic activity without physiological demands due to PA. Recovery was detected when the parasympathetic activity was predominant in the ANS.

In the categorization, second-by-second HRV indices, HRV-derived respiration rate, VO_2 calculated by HR, on-off kinetics, and parameter describing excess-post exercise VO_2 were used with neural network data modeling (for more details, see the white papers by Firstbeat Technologies Ltd.). The intensity of stress reaction was calculated from the HR, high frequency (0.15–0.4 Hz), and low frequency (0.04–0.15 Hz) components of HRV and respiratory variables. The intensity of stress was considered high when HR was elevated, HRV was reduced, and the frequency distribution of HRV was inconsistent because of changes in the respiratory period. The intensity of recovery was calculated from the HR and high frequency component of HRV, and it was considered to be high when HR was low and the high frequency component of HRV was high and regular. Thereafter, the software calculated HRV-derived variables to describe the state of the body (Saalasti 2003, Kettunen & Saalasti 2005, Kettunen & Saalasti 2008, Firstbeat Technologies Ltd. 2014). The data used in the analyses of the present dissertation consisted of successfully recorded days with an allowed maximum of 15 % (Studies I, II, IV) or 25 % (Study III) regarding the grade of detected and corrected artifacts in R–R intervals. The HRV and HRV-based variables used in the present dissertation are described in Table 1. The correlation coefficient between two consecutive workdays varied from 0.64 to 0.93 for HRV-derived variables of stress, and from 0.42 to 0.49 for HRV-derived variables of recovery during sleep (Study IV).

TABLE 1 Heart rate variability-based variables of stress and recovery used in the studies of the dissertation.

HRV-based stress variables	
Stress percentage	The percentage of 1-minute segments classified as stress during 24-hour period.
Stress percentage, working hours	The percentage of 1-minute segments classified as stress during working hours.
Stress index	The mean value of the magnitude of stress reactions in 1-minute segments classified as stress during 24-hour period.
HRV-based recovery (sleep) variables	
Stress balance	The difference between the total time of 1-minute segments classified as recovery during sleep and the total time of 1-minute segments classified as stress divided by the sum of the total time of 1-minute segments classified as recovery during sleep and the total time of 1-minute segments classified as stress. Values from 0.5 to 1 indicate good recovery; values from 0 to 0.5 indicate moderate recovery; and values from 0 to -1 indicate weak recovery.
Recovery index	The mean value of the magnitude of recovery reactions in 1-minute segments classified as recovery during the 4-hour window starting 30 min after going to bed.

HRV, heart rate variability

4.3.2 Subjective stress

In Studies I and II, subjective stress was assessed using the 14-item Perceived Stress Scale, PSS (Appendix 3) (Cohen, Kamarck & Mermelstein 1983), which measures the degree to which situations in an individual's life during the preceding month have been stressful. The responses are given on a 5-point scale ranging from 0 (never) to 4 (very often). Generally the PSS total score was calculated by reversing the scores of the seven positive items and then summarizing the scores of all 14 items. The Cronbach's alphas for the scale were as follows: 0.86 for baseline, 0.90 for 10 weeks, and 0.92 for 36 weeks.

4.4 Assessment of body composition

Body weight (kg) and height (cm) were measured in the morning in a laboratory setting (Studies I-III). In Study IV, weight and height were self-reported. The BMI was calculated as weight/height^2 (kg/m^2). In Study IV, the participants were then divided into the following groups: normal weight (18.5 to <25 kg/m^2), overweight (25 to <30 kg/m^2) and obese (30–40 kg/m^2). The whole body fat percentage was evaluated after fasting for 10–12 h using dual-energy X-ray absorptiometry (Study III) or by bioelectrical impedance analysis (Studies I, II).

4.5 Ethics of the study

In Studies I, II and III, all participants were informed about the initial study, and they signed written informed consent prior to any measurements. The initial studies were conducted according to the Declaration of Helsinki, and the initial study protocols were approved by the ethics committee of the Central Finland Health Care District.

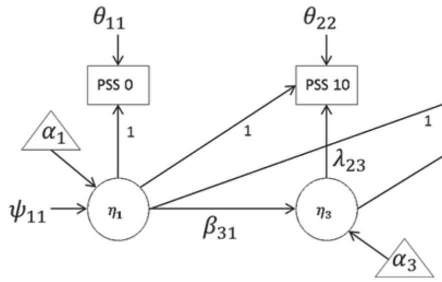
Firstbeat Technologies Ltd. extracted an anonymous data file from the registry for Study IV. Firstbeat Technologies Ltd. and service providers (e.g. occupational healthcare unit) who conducted the recordings for the employees signed an agreement providing Firstbeat Technologies Ltd. with the right to store the data in an anonymized form and to use it for development and research purposes with a statement that employers must inform their employees about this. This study was approved by the ethics committee of Tampere University Hospital.

4.6 Statistical methods

This dissertation included both cross-sectional and longitudinal analyses. In Studies I-III, statistical analyses were performed using Mplus program (version 5.21 in Study I, version 7.1 in Study II, version 7 in Study III) and MLR estimator which comprises maximum likelihood with robust standard errors and with scale-corrected chi-square test values correcting for the effect of non-normality. The few missing values were inferred to be missing at random (Muthén & Muthén 1998-2012). The model fit was evaluated using the chi-square (χ^2) test, root mean square error of approximation (RMSEA), comparative fit index (CFI), Tucker Lewis index (TLI), and standardized root mean square residual (SRMR). Non-significant χ^2 test, RMSEA lower than 0.06, CFI and TLI greater than 0.95, and SRMR lower than 0.08 indicated a good fitting model (Hu & Bentler 1999). In Study IV, data processing and statistical analyses were performed using R 3.2.2 version (The R Foundation for Statistical Computing). In each of the analyses, the level of significance was set at $p<0.05$. The statistical procedures used have been described in detail in the original studies.

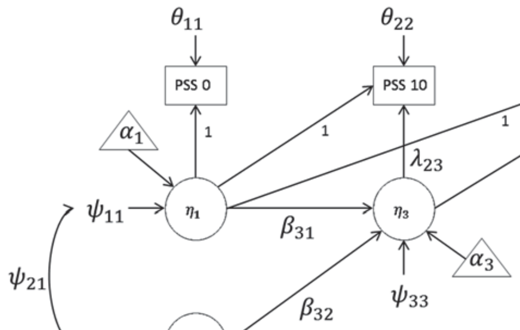
Confirmatory factor analysis (CFA) was used in Study I to analyze the measurement structure of the PSS score. Based on the results of the CFA, the latent factor model was used in the estimation of the correlations and in structural equation modeling (SEM) analysis to analyze the cross-sectional associations of HRV-based indices of stress and recovery (stress index and stress balance, respectively) with subjective stress.

Study II included longitudinal analyses. Latent growth curve modeling (LGM) (Bollen & Curran 2006) in the structural equation framework was used to analyze repeated measures over time. The LGM specifications for PSS over time are presented in Fig. 5. In the model, the factor loadings of the change were set to zero at first measuring point (PSS 0), set to one at third measuring point (PSS 36), and allowed to be freely estimated at the second measuring point (PSS 10). Furthermore, all intercepts of the observed variables were set to zero and the factor means/intercepts were freely estimated. By using this specification, the parallel LGM for PSS and one predictor variable (MET index, stress index, recovery index) at each time could be estimated (Fig. 6).



Perceived Stress Scale (PSS), residual variances (θ_{11}, θ_{22}, θ_{33}), estimated mean (α_1), variance (ψ_{11}), latent level factor (η_1), latent slope factor (η_3), regression coefficient (β_{31}), factor loading (λ_{23}), intercept (α_3)

FIGURE 5 A latent growth model for investigating the change in subjective stress at the three measurement points PSS 0, PSS 10, and PSS 36.



Perceived Stress Scale (PSS), residual variances (θ_{11}, θ_{22}, θ_{33}), estimated means (α_1, α_2), variances (ψ_{11} , ψ_{22}), residual variance (ψ_{33}), residual covariance (ψ_{21}), latent level factors (η_1, η_2), latent slope factor (η_3), regression coefficient (β_{31}, β_{32}), factor loading (λ_{23}), intercept (α_3)

FIGURE 6 A latent growth model for investigating the effect of the initial level of the predictor variables on the change in subjective stress at the three measurement points PSS 0, PSS 10, PSS 36.

In Study III, SEM was used to investigate if PA, cardiorespiratory fitness, and body composition were associated with HRV-based indicators of stress and recovery. In this study, the effect of clustered data (twins) was controlled using the type complex definition in Mplus. Body fat percentage, BMI, VO_{2max}, MET index were included as independent variables and HRV-derived stress and recovery variables were incorporated as dependent variables.

Kruskal-Wallis test was used in Study IV to analyze the between-group differences. For the descriptive statistics, the means and standard deviations (SD) of the outcome variables (variables derived from HRV) were calculated separately for men and women, and stratified based on PA, BMI and age. In Study IV, linear models were employed to study the effects of PA group, BMI and age on HRV-based stress and recovery variables. In the models, age and BMI were incorporated as continuous predictor variables and an objectively measured PA group was incorporated as a categorical predictor variable. The models were generated separately for men and women. The reference value for age was set to 18 years and for BMI to 18.5 kg/m^2. A simple linear least squares regression model (procedure *lm* in R) was applied to predict the stress percentage during the day. As confirmed by visual inspection, the assumption of linear regression considering the normal distribution of the residuals was not fulfilled for stress percentage during working hours, stress index and recovery index. Thus, a Box–Cox transformation was applied on these dependent variables (Osborne 2010). The Box–Cox coefficient was determined by maximizing the log-likelihood function and it was rounded to two decimal places before transformation. Tobit regression model (procedure *vglm* using iteratively reweighted least squares in R) was applied for modeling stress balance with a fixed lower and upper limit of −1 and 1, respectively.

5 RESULTS

5.1 Participant characteristics

Several data sets were utilized in the present dissertation. The basic characteristics of the participants are presented in Table 2. In Studies I and II, the participants were overweight and psychologically distressed with low inter-individual variance in their levels of PA. The participants' mean age was 48 years (45 for men; 48 for women), the mean BMI was 31.1 kg/m² (30.8 for men; 31.2 for women), the mean percentage of body fat was 38.6 (28.0 for men; 40.7 for women). The participants' mean level of PA based on a retrospective PA questionnaire was 3.2 MET-h/day (4.3. for men; 3.0 for women). The mean value for the PSS total score was 26.5 (26.2 for men; 26.5 for women). Of those 221 participants, 208 (94%) participated in the 10-week post-intervention measurements and 199 (90%) in the 36-week follow-up measurements. In the 10-week post-intervention measurement, the mean value of BMI was the same as that taken at the baseline, 31.1 kg/m² (30.8 for men; 31.2 for women), but decreased so that at the 36-week follow-up measurement it was 30.7 kg/m² (30.5 for men; 30.8 for women). The mean percentage of body fat decreased from baseline to 10-week (38.5 for all; 27.8 for men; 40.7 for women) and declined further at the 36-week assessment (37.8 for all; 27.2 for men; 39.9 for women) measurement. The mean value of PSS total score decreased from baseline to 10-week (23.9 for all; 22.1 for men; 24.3 for women) and then also further at the 36-week (21.9 for all; 21.3 for men; 22.1 for women) measurement.

In Study III, the participants were pooled together from two separate studies comprising a group of participants with extensive variability in PA, cardiorespiratory fitness and body composition. The participants' mean age was 34.1 years, the mean BMI was 26.0 kg/m², the mean percentage of body fat was 24.5, and their mean VO_{2max} was 39.6 ml/kg/min. The participants' mean level of PA based on a retrospective PA interview was 3.5 MET-h/day.

In Study IV, the participants' mean age was 45 years (for both men and women) and the mean BMI was 26.0 kg/m² (26.6 for men; 25.5 for women). The mean value of the subject's objectively-based monitoring of their weekly minutes of PA was 186 (246 for men; 142 for women).

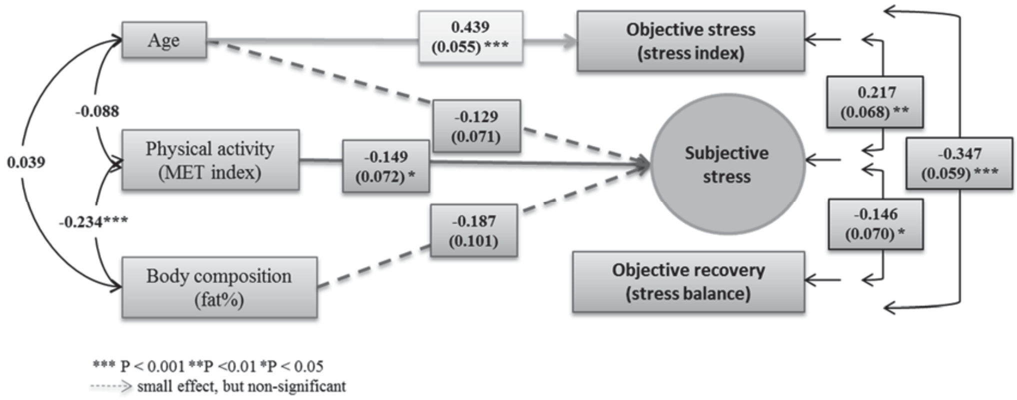
TABLE 2 Measurements and basic characteristics of the participants in the studies of the dissertation.

Studies	Age (yrs)	BMI (kg/m²)	Body fat (%)	Assessment of physical activity	Assessment of Perceived Stress
Elixir study; baseline (Study I & II)				Self-administered retrospective physical activity questionnaire (MET-h/day)	Perceived Stress Scale (PSS)
Men (N=36)	45.4±8.7	30.8±2.6	28.0±5.4	4.3±4.2	26.2±5.8
Women (N=185)	48.3±7.5	31.2±3.2	40.7±4.6	3.0±2.9	26.5±7.9
Elixir study; 10-week follow up (Study II)					Perceived Stress Scale (PSS)
Men (N=35)		30.8±2.7	27.8±5.2	3.9±3.6 (N=34)	22.1±7.3 (N=33)
Women (N=173)		31.2±3.3	40.7±4.7 (N=172)	3.0±2.6	24.3±8.4
Elixir study; 36-week follow up (Study II)					Perceived Stress Scale (PSS)
Men (N=34)		30.5±2.9	27.2±5.6	3.9±3.4 (N=31)	21.3±6.6 (N=31)
Women (N=165)		30.8±3.4	39.9±5.0	3.3±3.0 (N=163)	22.1±6.6
FitFatTwin study and the Body & Future Health study (Study III)				Retrospective physical activity interview (MET-h/day)	
Men (N=81)	34.1±3.0	26.0±3.4	24.5±7.3	3.5±3.7	NR
Data set of Firstbeat Ltd. (Study IV)				Ambulatory beat-to-beat R-R interval data (min/week)	
Men (N=6863)	44.5±9.9	26.6±3.5	NR	246±258	NR
Women (N=9412)	45.0±9.9	25.5±4.4	NR	142±189	NR

BMI, body mass index; MET, metabolic equivalent; NR, not reported
Data are shown as mean ± SD.

5.2 Association of subjective stress with heart rate variability-based stress (Studies I, II)

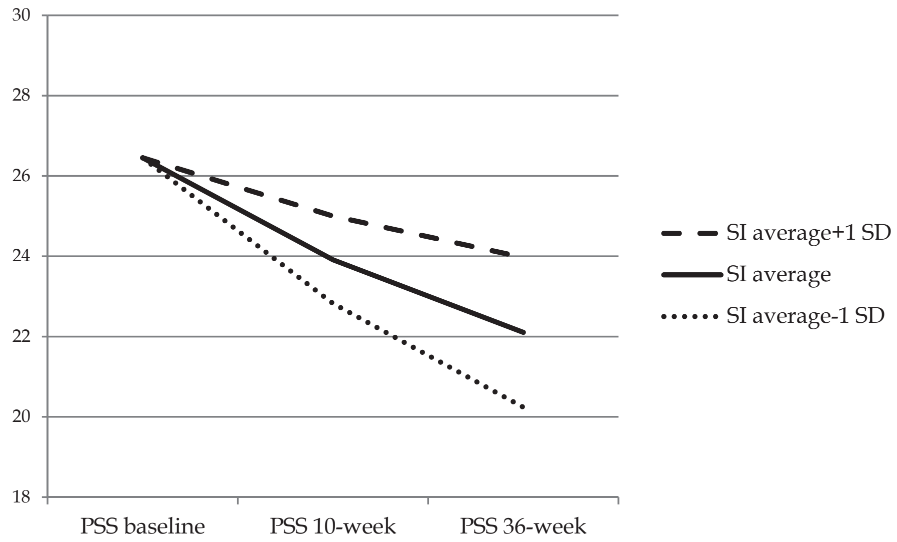
Study I In this study, PSS was used in the assessment of subjective stress. The structure of the factor used to analyze the association of subjective stress with HRV-based stress was based on the responses to the 14 questions of the PSS. This factor i.e. subjective stress, correlated with stress index (r=0.139, 95% CI 0.002 to 0.276, *P*=0.047) and with stress balance (r=-0.140, 95% CI -0.277 to -0.003, *P*=0.046) without any adjustments. Furthermore, subjective stress was associated with the stress index (residual r=0.209, 95% CI 0.075 to 0.343, *P*=0.002) and with the stress balance (residual r=-0.137, 95% CI -0.275 to 0.000, *P*=0.050) after adjustments for sex and age. Figure 7 presents the association of subjective stress with stress index and stress balance after adjustment for sex, age, PA, and body fat percentage. Subjective stress was associated with stress index (residual r=0.217, 95% CI 0.084 to 0.351, *P*=0.001) and stress balance (residual r=-0.146, 95% CI -0.283 to -0.009, *P*=0.037). The results were not influenced by further adjustment for alcohol consumption or regular medication.



Sex-adjusted associations are presented as standardized model results (estimate and standard error). Residual correlation and standard error between subjective stress and objective stress and recovery, and correlations between age, physical activity, and body composition are also presented.

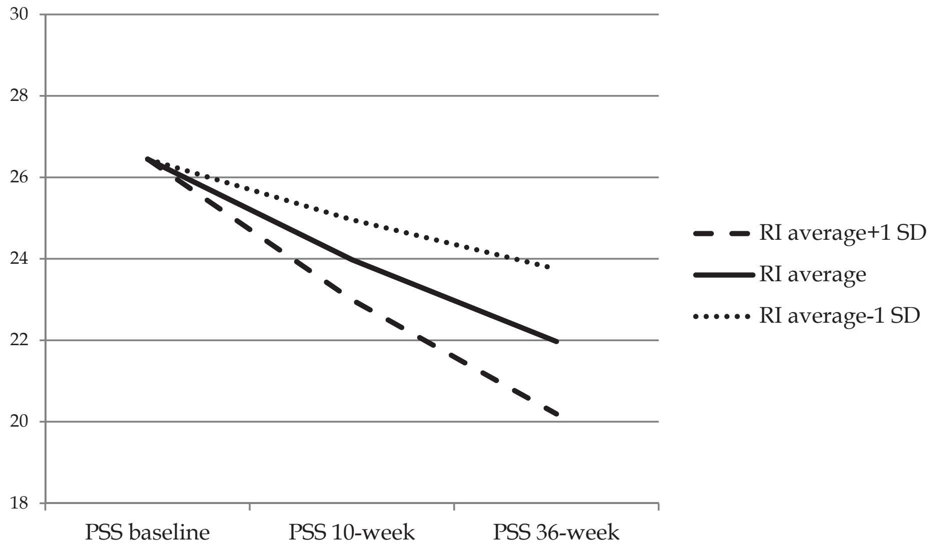
FIGURE 7 Associations of age, physical activity, and body composition with subjective stress, and with objective stress and recovery.

Study II This study investigated the association of subjective stress with objective HRV-based stress and had a longitudinal setting. The LGM analysis showed a significant individual variation in the latent level and slope factors, as well as a decline in the average PSS total score, but the average and individual levels of HRV-based stress and recovery indices were rather stable during the 9-month study period. Higher initial level (average +1 SD) of the stress index (standardized $\beta = 0.259$, $P = 0.001$) predicted a weaker decline in PSS (Fig. 8), whereas a higher initial level of the recovery index (standardized $\beta = -0.250$, $P = 0.004$) predicted a larger decline in PSS during the 9-month study period (Fig. 9). Adjustment for age, sex, current medication or changes in medication during the study period, alcohol consumption, or intervention group did not change the results. Age and current medication were significantly associated with the initial level of the stress index and recovery index; however, age and medication were not associated with changes in PSS over time.



PSS, Perceived Stress Scale; SI, stress index; SD standard deviation

FIGURE 8 The effect of the initial level of the stress index on the change in subjective stress during a 9-month study period.

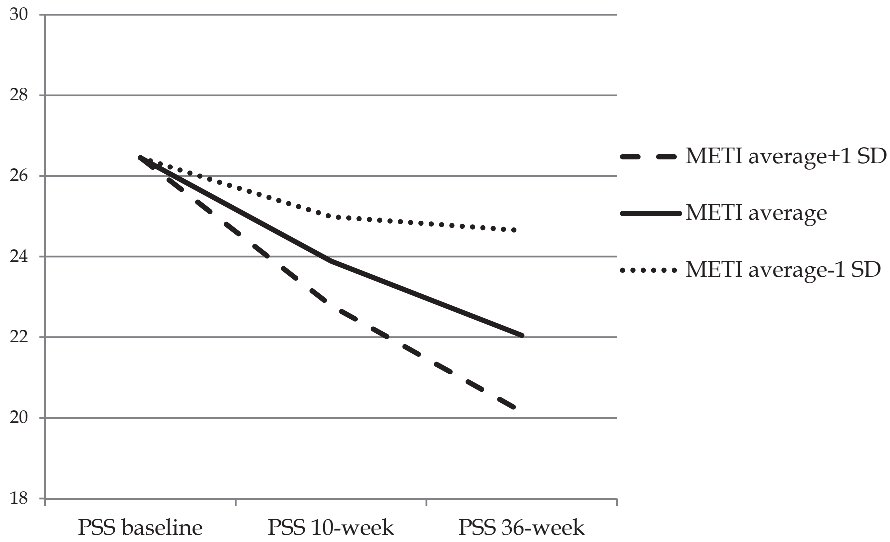


PSS, Perceived Stress Scale; RI, recovery index; SD, standard deviation

FIGURE 9 The effect of the initial level of the recovery index on the change in subjective stress during a 9-month study period.

5.3 Association of physical activity with stress (Studies II, III, IV)

Study II This study investigated the association of PA with stress and utilized a longitudinal setting. As reported above, the LGM analysis detected a significant individual variation in the latent level and slope factors, and a decline in the average PSS total score. The average and individual levels of MET index were rather stable during the 9-month study period. It was found that a higher level of PA was associated with larger decline in subjective stress over the long term i.e. a higher initial level of MET index (standardized $\beta = -0.266$, $P < 0.001$) predicted a larger decline in PSS during the 9-month study period (Fig. 10). Adjustment for age, sex, current medication or changes in medication during the study period, alcohol consumption, or intervention group did not affect the results.



METI, MET (metabolic equivalent) index; PSS, Perceived Stress Scale; SD, standard deviation

FIGURE 10 The effect of the initial level of the MET index on the change in subjective stress during a 9-month study period.

Study III This study assessed, both PA and cardiorespiratory fitness. The results are shown in Table 3. Better fitness and a higher level of PA were associated with a lower amount of stress reactions on workdays among participants with variability in their PA and fitness levels. Additionally, better fitness was associated with lower magnitude of stress reactions and better recovery (both lower amount and higher magnitude of recovery reactions) during sleep after the workday. Adjustment for age, alcohol consumption, working time, or sleeping time influenced the following results only minimally or modestly.

TABLE 3 Association of physical activity and cardiorespiratory fitness with the heart rate variability-derived indicators of stress and recovery.

	MET index (h/day)			$\mathbf{VO_{2max}}$		
	Standardized estimate (β)	Standard error (S.E.)	*P* Value	Standardized estimate (β)	Standard error (S.E.)	*P* Value
Stress (%), working hours	-0.304	0.113	<0.001	-0.311	0.132	0.019
Stress (%), 24 hours	-0.385	0.145	0.008	-0.416	0.126	0.001
Stress index, 24 hours	-0.096	0.124	0.440	-0.379	0.096	<0.001
Stress balance, sleep	0.097	0.089	0.255	0.270	0.073	<0.001
Recovery index, sleep	0.074	0.173	0.670	0.294	0.125	0.019

MET, metabolic equivalent; VO_{2max}, maximal oxygen consumption

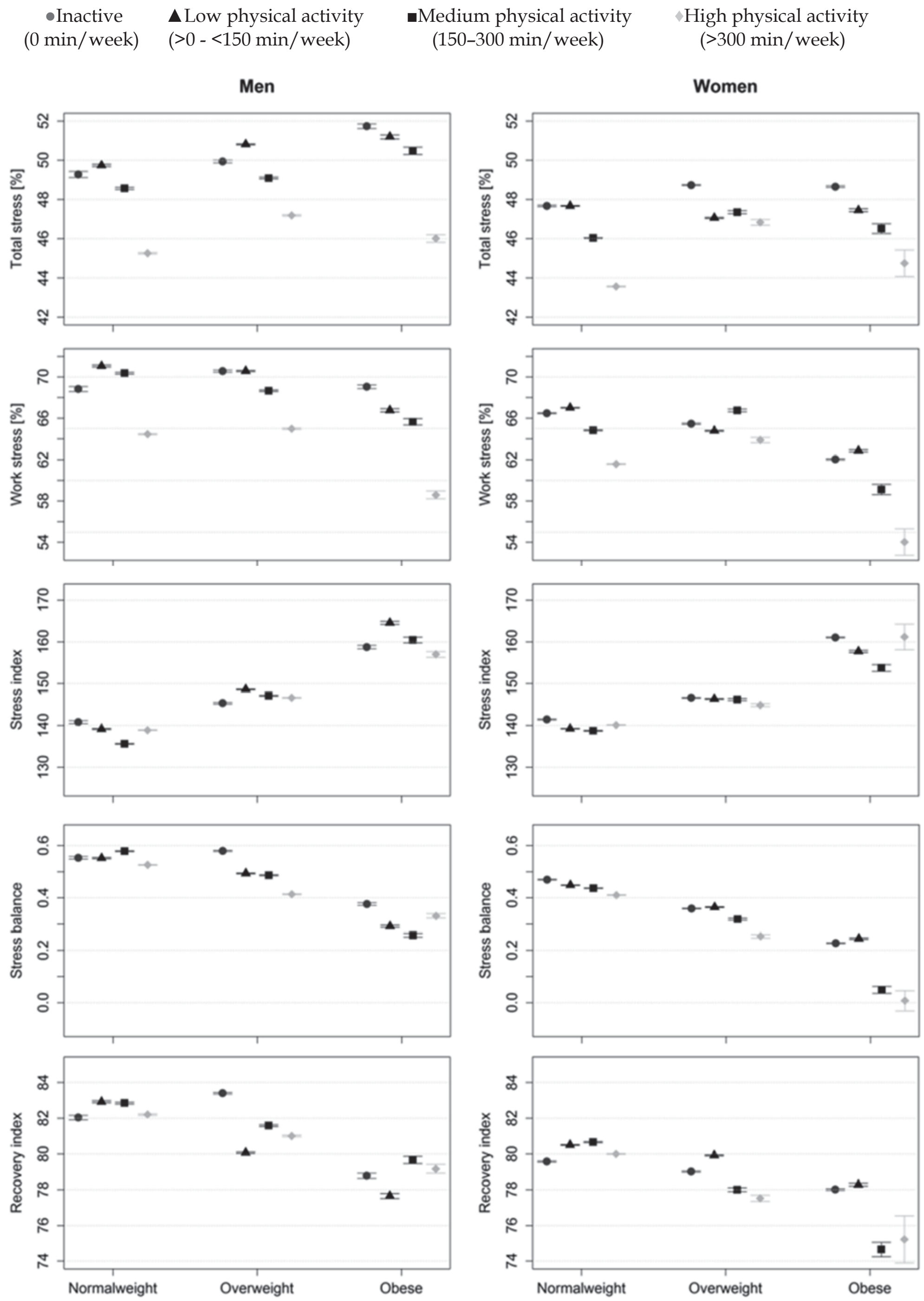
Study IV Here, PA was incorporated as a categorical variable. In the descriptive statistics, the means and SDs of the outcome variables were calculated separately for men and women, and stratified based on PA. Differences in HRV-derived stress and recovery variables between PA groups (Table 4) were statistically significant except for stress balance. In both men and women, the high PA group had the highest recovery index, and the lowest stress percentage (during the day and during working hours) and the lowest stress index.

The linear models (Table 5), including age, BMI and PA as predictor variables showed that high PA was associated with lower stress percentages (during workdays and working hours) and a lower stress balance, with the results being similar in men and women (P<0.001 for all). Figure 11 shows the effect of PA and BMI group on the stress and recovery variables with the effect of age controlled. The high PA group had the lowest mean stress percentage during the day and during working hours in all three BMI groups, after adjustment for age (Fig. 11).

TABLE 4 Characteristics of the heart rate variability-derived indicators of stress and recovery by physical activity groups.

Variable	Men (n=6863)					Women (n=9412)				
	Inactive (n=1117)	Low (n=1986)	Medium (n=1591)	High (n=2169)	*P*	Inactive (n=3055)	Low (n=3175)	Medium (n=1709)	High (n=1473)	*P*
Stress (%), 24 hours	50.0±15.0	50.5±13.7	49.1±13.7	46.4±13.3	<0.001	48.2±13.8	47.4±12.3	46.5±12.7	44.3±12.5	<0.001
Stress (%), working hours	68.5±23.3	69.6±21.5	69.3±21.3	65.1±23.5	<0.001	64.1±22.5	65.6±20.6	65.3±21.4	63.0±22.1	0.004
Stress index, 24 hours	155.1±46.3	151.1±44.9	142.7±41.3	139.1±39.0	<0.001	155.7±46.4	145.2±43.4	137.9±38.6	130.1±37.5	<0.001
Stress balance, sleep	0.49±0.54	0.47±0.55	0.50±0.53	0.48±0.53	0.227	0.35±0.57	0.39±0.52	0.38±0.55	0.39±0.55	0.175
Recovery index, sleep	80.6±14.1	80.1±15.8	82.1±14.2	82.2±15.8	<0.001	78.4±15.7	79.9±12.6	79.9±14.4	80.3±14.9	<0.001

Inactive (0 min/week), Low (>0 - <150 min/week), Medium (150–300 min/week), High (>300 min/week)
Data are shown as mean ± SD.
Kruskal–Wallis test was used to analyze the between−group differences.



Data are presented as age-controlled mean values and 99% CIs.
Normal weight (18.5 to <25 kg/m²), overweight (25 to <30 kg/m²) and obese (30–40 kg/m²).

FIGURE 11 Stress and recovery by physical activity and body mass index group.

TABLE 5 Results of the linear models.

	Men					Women				
	Parameter Estimate	95% CI Lower	Upper	*P* Value	*Variance explained (%)*	Parameter Estimate	95% CI Lower	Upper	*P* Value	*Variance explained (%)*
Stress (%), 24 hours [α]					2.356 [ψ]					1.476 [ψ]
Intercept	52.3153	50.7730	53.8575	<0.001		50.0658	48.9790	51.1527	<0.001	
Age (18 yrs=0)	−0.1263	−0.1600	−0.0926	<0.001	0.780 [τ]	−0.0869	−0.1151	−0.0587	<0.001	0.387 [τ]
BMI (18.5 kg/m²=0)	0.1541	0.0580	0.2502	0.002	0.144 [τ]	0.0909	0.0264	0.1553	0.006	0.081 [τ]
Physical activity level (inactive=0)					1.586 [τ]					1.050 [τ]
Low physical activity class	0.3235	−0.6903	1.3372	0.53		−0.8892	−1.5471	−0.2313	0.008	
Medium physical activity class	−1.1405	−2.2144	−0.0667	0.04		−1.9539	−2.7608	−1.1470	<0.001	
High physical activity class	−3.9695	−5.0062	−2.9328	<0.001		−4.3772	−5.2620	−3.4923	<0.001	
Stress (%), working hours [β]					4.152 [ψ]					1.721 [ψ]
Intercept	807.3480	777.0476	837.6483	<0.001		677.8091	656.0738	699.5443	<0.001	
Age (18 yrs=0)	−4.8729	−5.5355	−4.2103	<0.001	2.942 [τ]	−2.66482	−3.22838	−2.10127	<0.001	0.905 [τ]
BMI (18.5 kg/m²=0)	−4.6640	−6.5515	−2.7766	<0.001	0.341 [τ]	−4.54067	−5.82984	−3.25149	<0.001	0.504 [τ]
Physical activity level (inactive=0)					1.590 [τ]					0.584 [τ]
Low physical activity class	−5.5094	−25.4261	14.4073	0.59		−3.40975	−16.5664	9.746938	0.61	
Medium physical activity class	−24.7847	−45.8819	−3.6874	0.021		−17.9339	−34.0695	−1.79829	0.030	
High physical activity class	−85.2896	−105.6576	−64.9215	<0.001		−61.7878	−79.4833	−44.0923	<0.001	
Stress index, 24 hours [γ]					27.113 [ψ]					27.448 [ψ]
Intercept	1.2406	1.2403	1.2409	<0.001		1.2414	1.2412	1.2417	<0.001	
Age (18 yrs=0)	0.0001	0.0001	0.0001	<0.001	21.992 [τ]	0.0001	0.0001	0.0001	<0.001	19.655 [τ]
BMI (18.5 kg/m²=0)	0.0002	0.0001	0.0002	<0.001	3.819 [τ]	0.0001	0.0001	0.0001	<0.001	3.031 [τ]
Physical activity level (inactive=0)					0.115 [τ]					0.145 [τ]
Low physical activity class	0.0002	0.0000	0.0004	0.024		−0.0001	−0.0003	0.0000	0.031	
Medium physical activity class	0.0000	−0.0002	0.0002	0.91		−0.0002	−0.0004	−0.0001	0.002	
High physical activity class	0.0001	−0.0001	0.0003	0.47		−0.0003	−0.0004	−0.0001	0.002	
Stress balance, sleep [δ]					3.669 [ψ]					3.244 [ψ]
Intercept1	0.9975	0.9287	1.0663	<0.001		0.6166	0.5672	0.6661	<0.001	
Intercept2	−0.5292	−0.5503	−0.5082	<0.001		−0.5537	−0.5705	−0.5368	<0.001	
Age (18 yrs=0)	−0.0066	−0.0081	−0.0052	<0.001	1.153 [τ]	−0.0007	−0.0019	0.0006	0.31	0.006 [τ]
BMI (18.5 kg/m²=0)	−0.0273	−0.0315	−0.0231	<0.001	2.179 [τ]	−0.0253	−0.0282	−0.0224	<0.001	3.080 [τ]
Physical activity level (inactive=0)					0.445 [τ]					0.233 [τ]
Low physical activity class	−0.0715	−0.1162	−0.0269	0.002		−0.0126	−0.0423	0.0172	0.41	

Medium physical activity class	−0.0799	−0.1272	−0.0326	<0.001		−0.0572	−0.0937	−0.0207	0.002	
High physical activity class	−0.1327	−0.1784	−0.0870	<0.001		−0.0822	−0.1222	−0.0421	<0.001	
Recovery index, sleep [ε]					9.685 [ψ]					3.297 [ψ]
Intercept	592375.4298	573358.1497	611392.7100	<0.001		457913.8301	444648.7930	471178.8673	<0.001	
Age (18 yrs=0)	−5092.7330	−5508.5947	−4676.8712	<0.001	7.753 [τ]	−2100.7061	−2444.6430	−1756.7692	<0.001	1.501 [τ]
BMI (18.5 kg/m²=0)	−4825.0722	−6009.6783	−3640.4662	<0.001	0.921 [τ]	−4038.5841	−4825.3668	−3251.8014	<0.001	1.065 [τ]
Physical activity level (inactive=0)					0.154 [τ]					0.026 [τ]
Low physical activity class	−19214.5686	−31714.7934	−6714.3437	0.003		1051.0555	−6978.4656	9080.5766	0.80	
Medium physical activity class	−6153.1124	−19394.2693	7088.0445	0.36		−4452.2347	−14299.7786	5395.3093	0.38	
High physical activity class	−9653.5430	−22437.0465	3129.9606	0.14		−5732.9247	−16532.4796	5066.6302	0.30	

BMI, body mass index; CI, confidence interval; [α] Linear regression; [β] Box–Cox linear regression using transformation coefficient of 1.62; [γ] Box–Cox linear regression using transformation coefficient of −0.79; [δ] Tobit regression; [ε] Box–Cox linear regression using transformation coefficient of 3.18; [ψ] The proportion of variance explained by the whole model.; [τ] The proportion of variance explained by the predictor variable. Calculated as the difference between the proportion of variance explained by the whole model and the proportion of variance explained by a model including all the predictor variables, except for the predictor in question.

5.4 Association of body composition with stress (Studies III, IV)

Study III The results showing an association of body composition with the HRV-derived indicators of stress and recovery among participants including both normal-weight and overweight individuals are presented in Table 6. This study utilized both BMI and body fat percentage as measures of body composition. The results indicate that these two measures gave quite similar results with respect to the association between body composition and stress. Both BMI and body fat percentage were positively associated with stress percentage during the day as well as with the stress index ($p<0.01$ for all). Body fat percentage, but not BMI, was positively associated (standardized $\beta=0.306$, $P=0.005$) with stress percentage during working hours.

The HRV-based variables of recovery during night-time sleep (stress balance, recovery index) were negatively associated with body fat percentage ($p<0.05$ for all) and BMI ($p<0.01$ for all).

Adjustment for age, alcohol consumption, working time, or sleeping time influenced the results only minimally or modestly.

TABLE 6 Association of body composition with the heart rate variability-derived indicators of stress and recovery.

	Body fat%			**BMI**		
	Standardized estimate (β)	Standard error (S.E.)	*P* Value	Standardized estimate (β)	Standard error (S.E.)	*P* Value
Stress (%), working hours	0.306	0.108	0.005	0.162	0.086	0.060
Stress (%), 24 hours	0.442	0.101	<0.001	0.272	0.093	0.003
Stress index, 24 hours	0.422	0.115	<0.001	0.478	0.102	<0.001
Stress balance, sleep	-0.400	0.083	<0.001	-0.379	0.095	<0.001
Recovery index, sleep	-0.359	0.130	0.006	-0.395	0.102	<0.001

BMI, body mass index

Study IV In this study, BMI was used both as a categorical and continuous variable. In the descriptive statistics, the means and SDs of the outcome variables were calculated separately for men and women, and stratified according to the values of BMI. Differences in HRV-derived stress and recovery variables between BMI groups were statistically significant for both men and women (Table 7). Normal-weight individuals had the highest stress balance and recovery index, the lowest stress percentage during the day and the lowest stress index. Stress percentage during working hours was lowest in obese individuals.

In the linear models, BMI was included as a continuous predictor variable together with age and PA. A higher BMI value was associated with a higher stress index, and a lower stress balance and a poorer recovery index. These results were similar in men and women ($P<0.001$ for all). Figure 11 shows the effect of PA and BMI group on the stress and recovery variables with the effect of age controlled. Mean stress index values increased as the BMI group changed from normal weight to overweight and from being overweight to obese, regardless of the PA group.

TABLE 7 Characteristics of the heart rate variability-derived indicators of stress and recovery by body mass index groups.

	Men (n=6863)			Women (n=9412)		
	Normal weight (n=2475)	Overweight (n=3353)	Obese (n=1037)	Normal weight (n=5113)	Overweight (n=2765)	Obese (n=1534)
Stress (%), 24 hours	47.8±13.6	49.1±14.1	50.2±13.8	46.4±12.9	47.7±12.9	47.9±13.2
Stress (%), working hours	68.7±22.3	68.1±22.4	65.3±23.0	65.5±21.3	64.9±21.3	61.3±22.9
Stress index, 24 hours	134.8±35.0	148.8±41.8	163.7±54.8	136.2±39.0	150.0±41.3	164.8±53.3
Stress balance, sleep	0.56±0.50	0.48±0.53	0.31±0.59	0.44±0.52	0.34±0.55	0.21±0.59
Recovery index, sleep	83.16±13.81	80.93±15.11	78.13±17.86	80.50±13.57	78.78±14.30	77.34±16.60

Normal weight (18.5 to <25 kg/m^2), Overweight (25 to <30 kg/m^2), Obese (30–40 kg/m^2).
Data are shown as mean ± SD.
Kruskal–Wallis test was used to analyze the between−group differences. The difference was statistically significant ($P<0.001$) for all measures.

6 DISCUSSION

The present study investigated how PA, cardiorespiratory fitness, and body composition are associated with objectively measured HRV-based indicators of stress and recovery on workdays. Additionally, the association of subjective self-reported stress symptoms with HRV-based stress was evaluated. Furthermore, it was examined whether there is any association between PA and HRV-based stress and recovery with subjective stress in the long term. This study used a novel HRV-based method to assess the amount and intensity of stress and recovery. HRV has been proposed to be a valid way of assessing stress (Van Amelsvoort et al. 2000). Psychological stress exerts physiological effects on health through multiple mechanisms including alterations in the activity of the ANS. However, HRV is very individual and dynamic being modulated by sympathetic and parasympathetic activity of the ANS (Malliani et al. 1991, Task Force 1996). Previous findings about the associations examined here have been mainly based on traditional measures of HRV which represent the average level of the autonomic activity over different time periods. Thus, the novelty of the present findings stems from the HRV-based method that takes into account the dynamics and individuality of real-life HRV.

This study detected an association between subjective and objective HRV-based stress using a validated measure of perceived stress, PSS, as a measure of subjective stress. However, the findings suggested that these two aspects of stress react differently over the long term. There was a decline in subjective stress but no changes in HRV-based indices of stress and recovery during the 9-month study period. Nevertheless, these findings indicated that initial levels of HRV-based stress and recovery affected subjective stress in the long term. Some of the found associations relating subjective stress with objective HRV-based stress among the overweight and psychologically distressed participants with low inter-individual variation in their PA levels were rather weak and the clinical significance of the present findings should be evaluated in greater detail by examining participants with greater heterogeneity of stress, PA and body composition. However, the findings of this dissertation suggest that the HRV-based method for objective stress assessment provides an additional and relevant perspective for assessing stress. The focus of this dissertation in investigating the association of PA with stress was in objective HRV-based stress. The results support the beneficial effect of PA on health since there was evidence of lower HRV-based stress in physically active individuals. The findings of this dissertation support the hypothesis that fitness exerts a greater impact on the types of stress that impacts on HRV and especially on recovery from that kind of stress. Furthermore, this hypothesis is supported by the findings of this dissertation that there is an association of favorable body composition with lower amount and lower intensity of HRV-based stress on workdays and a better recovery during sleep.

6.1 Association of subjective stress with heart rate variability-based stress

This study found an association of higher subjective stress with higher HRV-based stress and reduced HRV-based recovery (Study I). Additionally, the results found that a lower initial level of HRV-based stress and a higher initial level of HRV-based recovery were linked with a larger decline in subjective stress over the long term (Study II). These findings support the recommendation that one should complement self-report measures with other objective measures (Semmer, Grebner & Elfering 2003). A wide range of different methods have been used in previous studies investigating the association of subjectively measured stress with HRV making it difficult to compare the present findings with those in the literature. However, in line with the present findings, several studies have found an association between higher subjective stress and lower HRV (Jarczok et al. 2013, Tonello et al. 2014). The putative mechanism behind the association is that work stress leads to vagal withdrawal and sympathetic predominance of the ANS (Malik & Camm 1993).

Eustress refers to “good” stress and is associated with both physical and mental challenges that promote health. However, chronic stress, irrespective of its origin and whether it is “good” or “bad”, is a risk factor for diseases. Thus, recovery plays an important role in stress management; adequate recovery is needed to maintain psychological and physiological reserves between work periods (Geurts & Sonnentag 2006). Sleep is an important part of recovery. During sleep, many functions of the individual are restored. It has been postulated that the lack of recovery is likely a greater health problem than the absolute level of stress (Lundberg 2005). This is supported by the findings of Vrijkotte et al. (2000); they also found HR and vagal tone to be independently associated with the incidence of mild hypertension and furthermore that the values occurring during sleep were more predictive for mild hypertension than the corresponding values while the individual was at work (Vrijkotte, van Doornen & de Geus 2000). This finding emphasizes the importance of recovery in stress management and supports the significance of the present finding

(Study I) i.e. there is an association between higher subjective stress and lower objective recovery. However, further studies will be needed to investigate the association between subjective stress and HRV-based recovery during sleep. For instance, Hynynen et al. (2011) found that low- and high-stress groups exhibited no differences in nocturnal traditional measures of HRV.

Study II investigated HRV-based stress and subjective stress and applied a longitudinal setting. The results showing a decline in subjective stress but no changes in the magnitude of HRV-based stress and recovery reactions suggest that these two aspects, subjectively and objectively measured stress, psychological and physiological stress, react differently over the long term. Nonetheless, the present findings suggest that the initial levels of the magnitude of HRV-based stress and recovery do reflect subjective stress over a longer time perspective. The results of Study II showed that a lower initial level of the magnitude of stress reactions as well as a higher initial level of the magnitude of recovery reactions were associated with larger decline in subjective stress. Previous studies have mainly focused on cross-sectional associations of subjective stress with HRV-based measures of objective stress but much fewer investigators have examined the association between HRV-based objective stress and subjective stress in longitudinal settings (Pärkkä et al. 2009, Melville et al. 2012, Cheema et al. 2013). The results of these published reports are in line with the present study suggesting that positive changes in an individual's subjective experience of stress may be associated with short time positive changes in his/her HRV profile. However, although objective and subjective stress react differently, it seems that HRV is more stable than the subjective experience of stress in the long term. This is support for the concept that although physiological and psychological responses to stress may be related they can be dissociated and differentiated from each other (Campbell & Ehlert 2012).

The findings of the dissertation support the idea that it would be advantageous to utilize both subjective and objective HRV-based methods in clinical practice. Self-report measures are influenced by several factors and there is a risk for measurement bias. Nonetheless, when attempting to measure how much stress an individual is experiencing, subjective assessment cannot be totally replaced by objective methods. Although self-reports always include the risk of subjective biases, replacing self-reports with stress-related physiological measurements is not recommended. However, objectively measured physiological stress may show evidence of stress accumulation before the individual experiences subjective stress. In the best case scenario, an objective measurement could alert the individual to undertake corrective actions in order to avoid more serious health consequences.

6.2 Association of physical activity with stress

Most working age people spend half of their waking hours at work and thus work has a major impact on their lives, and it may well determine the level of both daily PA and stress. The main interest of the dissertation was to investigate the association of PA with HRV-based stress on workdays. It was found that PA exerted a beneficial effect on HRV-based stress. The results showing an association of higher level of PA and better fitness with a lower amount of HRV-based stress and an association of better fitness with a lower magnitude of HRV-based stress were not unexpected. These outcomes were observed not only in a smaller study group, consisting of 81 males whose level of PA was based on self-reports and fitness level on sub-maximal exercise test, but also on a large sample of Finnish workers whose estimated level of PA was based on real-life HR monitoring. The present findings are in line with the previous reports i.e. both moderate and vigorous PA are associated with higher HRV (Rennie et al. 2003) and PA has been shown to lead to favorable changes in cardiac parasympathetic modulation and to increased HRV (Jurca et al. 2004, Pober, Braun & Freedson 2004, Pichot et al. 2005, Soares-Miranda et al. 2014).

As previously mentioned, sleep is a crucial part of recovery from stress. Regular PA has consistently been associated with better quality sleep (Driver & Taylor 2000). However, it has been suggested that the beginning of sleep may be disturbed if exercise is undertaken late at night because of the increased level of cardiac autonomic activity after exercise and the prolonged time needed for the recovery. The findings of Myllymäki et al. (2011) suggest that vigorous late-night exercise may influence the cardiac autonomic control of heart during the first sleeping hours. They found higher HR after the exercise day compared to the control day but no differences were found in HRV between the days (Myllymäki et al. 2011). Recovery of HRV is also dependent on training background, and type, intensity and duration of exercise (Kaikkonen, Rusko & Martinmäki 2008). The lower the level of physical fitness and the higher the intensity of exercise, the slower is the recovery of HRV after exercise (Seiler et al. 2007). Several studies have reported decreases in nocturnal HRV after maximal exercise (Furlan et al. 1993, Hautala et al. 2001, Hynynen et al. 2010). Hynynen et al. (2010) reported that even an exercise that was perceived as light and easy may have prolonged effects on nocturnal HRV during the following night. Those individuals who are physically more active may be eager to add to their PA level during a measurement period and exercise may take place late in the evening after the workday. Thus the findings of this study that there is an association of higher PA with a lower amount of HRV-based recovery (Study IV) or no association of PA with the amount or magnitude of night-time HRV-based recovery, but higher fitness was linked with better recovery (Study III) are somewhat as expected. To summarize, it appears that a high amount of PA on the same day may disturb night-time recovery, but over the long term, PA and good fitness enhance recovery during sleep. Previously it has been found that participating in sport activities after the workday has been thought to be highly important for recovery (Sonnentag & Jelden 2009). The findings of Sonnentag & Jelden (2009) showed that unfortunately after a stressful day, when an appropriate recovery activity such as enjoying some sport would be especially beneficial, people tend to be physically inactive and do not participate in sporting activities and thus do not enjoy the activity's property of enhancing recovery after that kind of workday. Positive recovery experiences, such as PA, during the day can reduce the strain level developing during the working hours and further enhance the quality of sleep. For instance, PA helps the individual to detach from work and thus sleep onset will be shorter and sleep quality will be improved when he/she is no longer obsessed with work-related issues after working hours or before going to bed. Additionally, it has been reported that the feelings of mastery and control connected to PA will give an individual a feeling of satisfaction and accomplishment and this will exert a positive impact on sleep quality (Sonnentag & Fritz 2007).

The assessment method of PA may have an impact on the observed associations as there may be variation in the level of estimated PA depending on whether subjective or objective methods are used. For instance, based on objective monitoring, only approximately every fourth adult Finn undertook the recommended amount of PA (Husu et al. 2014), which is about half of the value when this is estimated via self-reported PA. Furthermore, the findings of Hamer and Stamakis (2010) support the belief that the measurement method being used will influence the associations that will be found. They reported that objectively assessed moderate to vigorous PA was not associated with psychological health even though there was an association between self-reported PA and psychological health (Hamer & Stamatakis 2010).

Additionally, it is less clear how the putative beneficial effect of PA on the physiological stress impacts on an individual's psychological stress. Very few studies have investigated the association of the effects of PA on the changes in psychological and physiological stress and their results are inconsistent. For instance, Klaperski et al. (2013) showed that PA-induced changes in the physiological stress response did not extend to psychological stress responses. As previously discussed, the monitoring of HRV-based stress seems to indicate that over the long term, acute responses to PA are more stable than subjective feelings of stress. The present findings derived from longitudinal analyses indicate that PA has beneficial effects on an individual's ability to decrease the level of subjective stress (Study II). In summary, individuals who experience stress and at the same time are physically active benefit from their PA. They are more capable of lowering their level of subjective stress in comparison to those individuals who are inactive and psychologically stressed. In line with this study, a meta-analysis of workplace PA interventions suggested that an increase in PA may decrease work stress as well as exerting other health benefits (Conn et al. 2009). Furthermore, Kouvonen et al. (2013) found that increased work-related stress was weakly associated with decreased PA during the 6–8 year follow-up. Based on the findings of the present study, it is not possible to draw any conclusions about the effect of increased PA on subjective or objective stress as the study participants stated that there was no significant change in their level of PA. It can be suggested that the greatest improvements in health would be experienced when the least fit individuals become physically active and also that people who engage in exercise at levels above the general PA recommendations are likely to gain further health benefits (Warburton, Nicol & Bredin 2006).

Furthermore, the findings of this dissertation (Studies III, IV) support the idea that it is fitness rather than the level of PA that has a greater impact on HRV-based stress and especially on HRV-based recovery from stress (Table 8). Both higher levels of PA and fitness were associated with a lower amount of HRV-based stress reactions, but in addition, better fitness was found to be associated with lower intensity of stress reactions and with better night-time recovery. The results emphasize the important role of good fitness in promoting the recovery from daytime stress; this has been postulated as being more important for health (Vrijkotte, van Doornen & de Geus 2000, Lundberg 2005). Additionally, previously it has been found that the dose-response relationship between fitness and health outcomes would be higher than that between PA and health outcomes (Blair, Cheng & Holder 2001). However, PA is needed for improving fitness. The Cross Stressor Adaptation Theory provides an explanation for the observed associations. According to this theory, PA can help the individual to build resources to buffer the negative effects of stress and promote his/her recovery from stress. In other words, PA can help the individual to develop fitness. Furthermore, this increased fitness, which is associated with a greater dominance of the parasympathetic arm of the ANS under resting conditions, is related to lower stress vulnerability as well as promoting recovery from stress (Porges 1995). This supports the concept that PA in the long term has beneficial effects on health, in terms of lower HRV based stress and better recovery. Furthermore, by measuring HRV based indices, one should gain a better perspective of the relationship between increased fitness and stress. The results of the dissertation suggest that an employer should support employees' PA as a way of enhancing their wellbeing. It has been found that physical inactivity is associated with absenteeism (Birdee et al. 2013); one trial indicated that a PA intervention at the organizational level could reduce absenteeism (Bhui et al. 2012). The ability to objectively monitor stress, recovery and PA of a company's employees may well be a promising tool to modify their health behavior. Today, everyone is aware of the PA recommendations; this information is provided everywhere, for example in television, newspapers and social media. Thus, the failure to undertake PA cannot be a consequence of ignorance of its benefits (Hirvonen et al. 2012). In this respect, it is apparent that new methods are needed to convince individuals to change their behavior.

TABLE 8 Summary of the observed associations of physical activity, cardio-respiratory fitness and body composition with heart rate variability-based stress and recovery.

	Amount of HRV-based stress	Magnitude of HRV-based stress reactions	Amount of HRV-based recovery	Magnitude of HRV-based recovery reactions
Physical activity (Study III/Study IV)	-/-	no/no	-/no	no/no
Cardiorespiratory fitness (Study III)	-	-	+	+
Body composition (Study III/Study IV)	+/+	+/+	-/-	-/-

HRV, heart rate variability; +, positive association; -, negative association; no, no association

6.3 Association of body composition with stress

Previously, the studies investigating the association of body composition with stress and recovery have mainly used subjective methods to estimate the level of stress. However, the effect of obesity on ANS has been another focus of interest. This study utilized both BMI and body fat percentage as measures of body composition. These two measures associated rather similarly with the HRV-based indicators of stress and recovery, suggesting that BMI, a parameter that is straightforward to measure can be used as an indicator of body composition in clinical work.

One finding emerging from this dissertation is that there is an association between favorable body composition and lower amount and intensity of HRV-based stress on workdays; this is in line with previous studies using traditional measures of HRV. Previously, HRV profiles have been claimed to be relatively poor among obese individuals (Zahorska-Markiewicz et al. 1993, Karason et al. 1999, Kim et al. 2005, Millis et al. 2010) and to improve after weight loss (Karason et al. 1999, Rissanen, Franssila-Kallunki & Rissanen 2001). In addition to stress during the workday, this study investigated the association of body composition with HRV-based stress specifically during working hours but the findings are somewhat inconsistent. Unfavorable body composition, as reflected by a high body fat percentage in Study III, was associated with a higher amount of stress during working hours among men. In contrast, Study IV found an association between higher BMI and a lower amount of HRV-based stress during working hours among a large sample of Finnish workers. Previously, it has been suggested that individuals with lower socioeconomic status are more likely to be obese and more likely to be in physically active employment than their counterparts with higher socioeconomic statuses (McLaren 2007, Lallukka et al. 2008). Thus, time spent in PA leads to less time for other physiological body states, such as stress, during working hours and this may explain the latter finding (Study IV). Another possible explanation for these findings is that among obese individuals, the physiological state of the body is detected as PA instead of stress, with HR increasing and HRV declining. Therefore, caution is required when interpreting these results. However, the association of body composition with HRV-based stress during working hours should be studied further.

The findings of this study derived from the night-time HRV-based indicators of recovery are consistent and support the hypothesis that an unfavorable body composition exerts a negative impact on HRV. Furthermore, the finding that BMI was more strongly associated with the amount of recovery than PA or age (Study IV) highlights the importance of body composition in relation to recovery from stress. However, there is convincing evidence that there is an association between PA and weight gain (Reiner et al. 2013). Thus, the results of the present study about the effects of favorable body composition further support the belief that PA has beneficial effects on HRV-based stress. However, the causality of the relationship between PA and obesity is not clear; is physical inactivity a contributor to obesity or vice versa nor is it evident the extent to which any association is causal (Bauman et al. 2012, Reiner et al. 2013). It is apparent that obesity is a complex condition with many causal contributors, such as other behavioral factors in addition to PA, socioeconomic, environmental, and genetic factors (Qi & Cho 2008).

In general, the evidence is weak and inconsistent that there would be a link between psychosocial factors at work and weight-related outcomes (Solovieva et al. 2013). However, based on previous (Zahorska-Markiewicz et al. 1993, Rissanen, Franssila-Kallunki & Rissanen 2001) and the present results, the association between obesity and HRV and HRV-based stress seems to be more consistent. In this dissertation, fat distribution was not taken into account even although it may have a role in relation to the HRV profile (Gao et al. 1996, Grassi et al. 2004).

6.4 Methodological considerations

This dissertation utilized several data sets. In Studies I and II, the participants were psychologically distressed and overweight and thus represented an appropriate study group for investigating the association of subjective stress with objective stress and recovery. Furthermore, the participants represent a group of Finnish workers with different occupations, mainly commercial and office workers. However due to the specific characteristics of this study population, the findings derived from Studies I and II can be generalized only to overweight individuals with psychological distress. The observed results about the beneficial effect of PA and fitness on HRV-based stress among participants who participated in clinical measurements (Study III) were confirmed among over 16 000 Finnish workers (Study IV). The strength of this dissertation is the very large sample in Study IV which included both non-manual and manual labor employees. However, as Study IV was a data-mining study, detailed individual information about the participants was not available. Most of the workers were apparently healthy; however, the inclusion of individuals with chronic diseases and/or on medications may have had an effect on HRV. However, the large sample size should have compensated for these inclusions, and the results were statistically significant. On the other hand, large sample sizes may lead to the appearance of statistically significant differences also in cases when their clinical significance is low.

It is strength of the present study that it utilized novel technology and that the HRV data was recorded in real-life settings over a rather long time period, usually two workdays and one day off work. The majority of studies which have investigated work stress have applied short term analyses of HRV. It has been postulated that long term HRV recordings during real-life activities could reveal new aspects in stress studies (Van Amelsvoort et al. 2000, Grossman & Taylor 2007). Traditional measures of HRV are sensitive to several confounding factors. For instance, age, diseases like hypertension and diabetes, ethnicity, medication, smoking, alcohol and caffeine consumption, level of PA, and breathing are potential confounders in HRV studies (Task Force 1996, Jarczok et al. 2013). Due to the limited possibility of incorporating traditional measures of HRV into the ever-changing and uncontrollable real-life setting, it is important to develop methods that exploit HRV data and are able to provide valuable information on stress and recovery as the subjects go about their everyday lives. The inter-day reliability of the HRV-derived variables of stress and recovery used in this study was found to be high. Additionally, these variables correlated highly with traditional measures of HRV. The validated HRV-based method (Rusko et al. 2006, Uusitalo et al. 2011) used in this study utilized both HRV and additional HRV-derived information in producing knowledge of stress and recovery that is not available from the basic HRV measures since these represent the average level of the autonomic activity over a period of the time. This knowledge can also be utilized in supporting lifestyle changes. HRV-based methods that take individual characteristics into account and provide easily understandable variables of stress and recovery during day and night can be informative and potentially represent suitable measures for field studies and clinical trials. Individual written feedback together with verbal feedback and discussion of the HRV recording results would be optimal (Appendix 4; an example of the feedback the participants received). It should be noted here that the method used in this study did not distinguish eustress from distress. However, it may be impractical to try to differentiate between these two types of stress. The physiological response to both forms of stress is similar and if this response is prolonged, it has adverse health effects.

In addition to HRV-based assessment of stress on workdays, subjective methods were used to assess the level of stress. Even though it is known that subjective assessments may include some reporting bias, it is a commonly used way of measuring stress. A simple questionnaire has been the most frequently utilized instrument but this has been widely criticized because it relies on individual self-reporting. In the present study, subjective stress was assessed by PSS. This scale has been found to be a reliable and valid measure of perceived stress. PSS assesses subjective stress during the preceding month. Thus, it is important to appreciate that the present results provide information about the association of perceived stress during the preceding month with the objective HRV-based stress and recovery on (mainly) two days at the end of this month. The HRV-based values represent a physiological measurement and provide objective data; these should be more reliable as they are not affected by an individual's desire to impress nor are they influenced by social context or emotions (Kompier 2005). Therefore, it is reasonable and important to develop objective measures of stress that reflect the physiological burden of stress. Nonetheless, it is clearly advantageous to combine subjective and objective measures of stress as they complement each other.

Measurement method may have a significant impact on the measured levels of PA. Self-reported levels of PA have been found to be both higher and lower than objectively measured levels of PA. If one peruses the existing literature, then it is evident that there is a need for valid, accurate and reliable measures of PA in assessing current and changing PA levels, and the relationships between PA and health outcomes (Prince et al. 2008). In this study, the assessment of PA was based on both subjective self-report and objective ambulatory beat-to-beat R-R interval recording. It is important to take into account that the self-report, accomplished as an interview or questionnaire, assessed PA during the preceding month. In contrast, the beat-to-beat R-R interval recording-based estimation of PA was sampled during the same days as the objective measurement of stress. The validated questionnaire that was used inquired about the long term level of leisure-time PA - this may give more reliable information about an individual's PA than an objective measurement from a short period. However, it can be considered as a strength of this study that in addition to the subjective assessment of the level of PA, the amount of weekly PA was estimated based on the objective measurement of PA periods lasting over ten minutes and the measurement period included at least one workday and one day off work. During this kind of short time assessment, the individual could display a tendency to be more active than would normally be the case. However, three days of data collection has been postulated to be sufficient to achieve valid results (Tudor-Locke et al. 2005) and it has been recommended that the recording period should include both weekdays and weekend days as activity levels may vary considerably between these days of the week (Warren et al. 2010). The validated ambulatory beat-to-beat R-R interval-based method (Smolander et al. 2011, Mutikainen et al. 2014) used to assess the amount and intensity of PA has been shown to provide more accurate estimates of the intensity of PA than can be acquired from HR data (Smolander et al. 2011, Mutikainen et al. 2014). Furthermore, compared to accelerometer-based data, HR–based monitoring methods are better for determining the intensity of different types of PA in real-life. Accelerometers cannot account for all activities, such as cycling, stair use, or activities that require lifting a load. Additionally, upper-body activities are neglected if the accelerometer is worn on the hip or lower-back (Strath et al. 2013). However, accelerometer-based objective monitoring methods may be more reliable than HR–based techniques in monitoring low to very low intensity PA (Strath et al. 2013).

BMI and body fat percentage were used as measures of overweight in the present study. Body fat percentage was estimated by both bioimpedance analysis and DXA. DXA was initially designed to measure bone mass but it has been shown to be both accurate and precise and it is increasingly being used for measuring body composition in clinical settings. DXA is considered superior to many other methods as it offers a quick and easy assessment of body fat, lean mass and bone mineral density (Andreoli et al. 2009). However, BMI and total body fat percentage are considered as measures of general adiposity. Abdominal obesity is more closely associated than gluteofemoral obesity with the risk of several chronic diseases and there are large studies indicating that indicators of abdominal obesity, such as waist circumference or the waist-hip ratio may be better predictors than BMI of the risk of disease (Pischon et al. 2008). However, the findings of a previous study which examined the association of BMI, waist girth, and waist-hip-ratio with the risk of death among over 35 000 participants from nine European countries suggest that general and abdominal adiposity are both associated with the risk of death. Furthermore, those results support the use of waist circumference or waist-to-hip ratio in addition to BMI in the assessments of mortality risk, particularly among persons with a low BMI (Pischon et al. 2008). In their review article, Deurenberg et al. (2002) stated that while it is obvious that the BMI is a reasonably good indicator for body fat percentage, it is necessary to be aware that the relationship between BMI and body fat percentage is age-, gender- and ethnicity-dependent.

6.5 Implications and future directions

This study found objective HRV-based measures of stress to be associated with risk factors of cardiovascular diseases; low PA, overweight and low cardiorespiratory fitness. Thus it would be interesting to carry out a prospective study on HRV-based stress and cardiovascular events. Assessment of HRV is a promising clinical tool for assessing health and identifying health impairments. However, due to the limited applicability of the traditional measures of HRV to manage constantly changing and uncontrollable real-life settings, it is important to develop methods that collect HRV data and are able to provide valuable information on stress and recovery in an individual’s everyday life. By utilizing both HRV and additional HRV-derived information, it is possible to acquire knowledge of physiological states, such as stress and recovery that is not available from the basic HRV measures which represent the average level of the autonomic activity over a period of the time. The presently described method for objective stress assessment provides an additional and important dimension for estimating the level of stress. These results provide important information about the efforts needed for stress management to improve an individual's health and wellbeing. This information could be applied for devising new health policies, and the results may well be adapted so that health-care professionals could utilize them in their daily clinical work. Furthermore, the results provide valuable information for the development of stress assessment methods. Additionally, it is important that new technologies and PA measurement methods are developed as they may have considerable financial implications (Hallal et al. 2012).

This study did not assess the role of sedentary behavior on HRV-based stress. Sedentary behavior refers to activities of less than 1.5 METs performed in a sitting or lying position (Pate, O'Neill & Lobelo 2008) and it is a distinct concept from physical inactivity (Sedentary Behaviour Research Network 2012). Today, more and more emphasis is being placed on understanding the detrimental effects of sedentary behavior. Future studies should assess the association of PA with stress taking into account the impact of sedentary behavior. For example, even though an individual would comply with PA recommendations, her/his day may include many hours of sedentary behavior which has been suggested to be a risk factor for depression, irrespective of whether she/he undertakes moderate/vigorous PA (Zhai, Zhang & Zhang 2015). This finding may apply to associations of sedentary behavior with stress. In the future, the development of the objective measurement methods producing both HR and accelerometer data might clarify the association between PA and stress as well as taking into account the influence of sedentary behavior.

The effect of the timing of PA on night-time recovery should be studied further and it would be interesting to confirm the findings of the present study using the same objective measurement of PA but instead of absolute cutoff points at different intensity levels, the relative (i.e., relative to individual's estimated VO_{2max}) cutoff points would be used. It is well known that maximal exercise capacity in poorly fit individuals, in particular among aged, obese or individuals with chronic diseases, may be lower than the recommended absolute intensity level of vigorous PA. Consequently, it is obvious that individuals who cannot reach the recommended intensity level, do not have so much activity in their objective recordings. Thus, objectively measured absolute volume of PA may differ significantly from the relative volumes of PA. The same absolute exercise intensity may be a warm-up for one person but requires a maximal effort by another person. Previous studies have recognized this by adjusting the intensity of PA relative to some maximal physiological response, such as maximal HR or VO_{2max} (Howley 2001, Hautala et al. 2012). For instance, in PA counselling, it is recommended that the intensity of PA should be tailored individually (Garber et al. 2011).

Furthermore, it would be interesting to examine more precisely the effect of the length of working hours on stress. For example, there is evidence that working for over 60 hours per week is associated with obesity (Jang et al. 2013). There is a demand by employers and some political leaders that there should be a lengthening of working hours, for this reason it would be desirable to gather reliable data about the possible adverse health effects of these kinds of changes. Additionally, it would have been interesting to study the effect of socioeconomic status on the observed associations. There is evidence for a clear occupational class gradient in BMI among Finnish employees (Silventoinen et al. 2013). Additionally, it has been suggested that high level of physical demands in the workplace are positively associated with high BMI (Lallukka et al. 2008).

To summarize, more research is needed to clarify the relationships between increased PA, HRV profiles and subjective stress. Randomized controlled trials investigating these associations are warranted. However, it has proved challenging to increase people's PA and worksite PA interventions have been claimed to be associated with only relatively modest increases in PA (Bravata et al. 2007). However, this study found evidence for the positive effects of PA and favorable body composition on HRV-based stress. As confirmed here, the beneficial effects of PA on health are evident and therefore these results may help convince employers to invest greater resources to improve the PA of their employees.

7 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions of this dissertation are:

1. Subjective self-reported stress was associated with objective HRV-based stress and recovery from stress among overweight and psychologically distressed individuals. The findings indicate that this novel HRV-based method for objective stress assessment provides an additional and important aspect to stress assessment.

2. Among overweight and psychologically distressed individuals, the initial levels of PA and HRV-based indicators of stress and recovery were associated with an overall change in subjective stress during a 9-month study period, suggesting that high PA and objectively-assessed low stress and good recovery from stress have positive effects on changes in subjectively experienced stress over the long term.

3. Higher PA and cardiorespiratory fitness, and favorable body composition were associated with lower HRV- based stress on workdays among men. Fitness, not only cardiorespiratory fitness but also body composition, seems to be a more significant factor than PA for HRV-based stress, especially for recovery from stress.

4. Among a large sample of Finnish employees, including both men and women, objectively measured high PA was associated with a lower amount of HRV-based stress on workdays. The results suggest that a PA level exceeding the general PA recommendations has positive effects on health since it is related to a lower amount of HRV-based stress.

YHTEENVETO (FINNISH SUMMARY)

Vapaa-ajan liikunta-aktiivisuuden yhteys sykevälivaihtelun avulla mitattuun työpäivän stressiin

Liikkumattomuus ja ylipaino sekä työperäinen stressi ovat laajuudessaan merkittäviä ongelmia ja haasteita nykypäivän yhteiskunnassa. Näihin terveydelle haitallisiin tekijöihin vaikuttaminen ja niiden esiintyvyyden vähentäminen on laajalti terveydenhuollon alan ammattilaisten ja tutkijoiden mielenkiinnon kohteena. Useimmat työikäiset ihmiset viettävät noin puolet valveillaoloajastaan työssä. Täten työllä on merkittävä vaikutus työikäisten elämään, päivittäiseen liikunta-aktiivisuuteen ja päivittäisen stressin määrään.

Liikunnalla on osoitettu olevan monia positiivisia vaikutuksia terveyteen. Se on merkittävä tekijä useiden pitkäaikaissairauksien ennaltaehkäisyssä ja hoidossa sekä ennenaikaisen kuolemanriskin vähentämisessä. Liikunnalla on suotuisia vaikutuksia mielenterveyteen ja henkiseen hyvinvointiin, myös stressinhallintaan. Liikunnan positiivisten terveysvaikutusten saavuttamiseksi liikunnan tulisi olla säännöllistä ja määrällisesti riittävää. Valitettavasti niin maailmanlaajuisesti kuin Suomessakin huomattava osuus väestöstä liikkuu liian vähän. Liikkumattomuus on merkittävä ongelma erityisesti kehittyneissä maissa, joissa teknologia on muuttanut työn luonnetta niin, että työ sisältää nykyisin useimmiten hyvin vähän fyysistä aktiivisuutta. Näin ollen vapaa-ajan liikunnan merkitys terveyden kannalta on lisääntynyt.

Tavallisimmin stressi ajatellaan subjektiivisena stressikokemuksena, jota arvioidaan subjektiivisin menetelmin, kuten kyselyllä. Stressi sisältää psykologisen subjektiivisen puolen lisäksi myös fysiologisen objektiivisen puolen, jota voidaan arvioida objektiivisesti elimistön fysiologisia toimintoja mittaamalla. Sykevälivaihtelun on todettu olevan käyttökelpoinen objektiivinen menetelmä. Sykevälivaihtelulla tarkoitetaan peräkkäisten sydämen lyöntien välisen ajan vaihtelua. Tyypillisesti terveen henkilön hyvää autonomisen hermoston säätelykykyä kuvaa suuri sykevälivaihtelu. Pieni sykevälivaihtelu on merkki epänormaalista ja riittämättömästä autonomisen hermoston sopeutumiskyvystä. Stressi aiheuttaa autonomisen hermoston sympaattisen osan toiminnan voimistumisen suhteessa sen parasympaattisen osan toimintaan ja on yhteydessä pieneen sykevälivaihteluun. Palautuminen on yhteydessä autonomisen hermoston parasympaattisen osan toiminnan voimistumiseen ja suureen sykevälivaihteluun. Palautumisen seurauksena fysiologinen stressivaste häviää, joten palautuminen on keskeinen osa stressinhallintaa.

Suurin osa aiemmista sykevälivaihtelu-menetelmää hyödyntäneistä tutkimuksista on käyttänyt perinteisiä aika- ja taajuusanalyyseistä saatavia muuttujia. Sykevälivaihtelu ja nämä perinteiset muuttujat ovat hyvin yksilöllisiä mikä rajoittaa niiden käyttöä stressin arvioinnissa ja kliinisessä työssä. Kehittyneiden menetelmien ansiosta nykyään on mahdollista luoda yksilöllisestä sykkeestä ja sykevälivaihtelusta johdettuja stressin ja

palautumisen muuttujia, jotka ovat informatiivisia ja käyttökelpoisia esimerkiksi yksilön elämäntapamuutoksen tukemisessa.

Tämän väitöskirjatutkimuksen tarkoituksena oli selvittää sykevälivaihteluun pohjautuvan menetelmän käytettävyyttä stressin sekä liikunta-aktiivisuuden ja stressin välisen yhteyden arvioinnissa. Tutkimus pyrki selvittämään subjektiivisen ja sykevälivaihteluun pohjautuvan objektiivisesti mitatun stressin yhteyttä. Tutkimuksen päätarkoituksena oli selvittää kuinka liikunta-aktiivisuus ja siihen kytkeytyvät fyysinen kunto ja kehonkoostumus ovat yhteydessä työpäivän aikaiseen stressiin ja seuraavan yön palautumiseen. Tutkimuksessa hyödynnettiin sekä poikkileikkaus- että pitkittäisasetelmaa.

Tässä tutkimuksessa käytettiin useampaa eri aineistoa. Subjektiivisen ja objektiivisesti mitatun stressin yhteyden selvittämisessä hyödynnettiin satunnaistetun ja kontrolloidun Eliksiirit-interventiotutkimuksen ylipainoisista ja psykologisesti stressaantuneista yksilöistä koostuvaa tutkittavien joukkoa. Samaa aineistoa hyödynnettiin myös pitkittäisanalyyseissä. Liikunta-aktiivisuuden, fyysisen kunnon ja kehonkoostumuksen yhteyttä objektiivisesti mitattuun stressiin selvitettiin aineistossa, joka sisälsi sekä liikkumattomia, huonokuntoisia että paljon liikkuvia, hyväkuntoisia miehiä. Tämä aineisto saatiin yhdistämällä kaksi eri tutkimusaineistoa. Lisäksi liikunta-aktiivisuuden yhteyttä objektiivisesti mitattuun stressiin selvitettiin suuressa Firstbeat Technologies Oy:n (Jyväskylä) yritystyössään keräämässä aineistossa, joka koostui vuosina 2007-2015 yrityksen palvelua hyödyntäneiden työnantajien työntekijöilleen tarjoamista työhyvinvoinnin arvioinneista. Subjektiivista stressiä arvioitiin PSS-kyselyllä (Perceived Stress Scale). Objektiivisesti mitattu stressi määritettiin tyypillisesti 1-3 vuorokautta kestäneestä tavallisen elämän yhteydessä nauhoitetusta sykevälivaihtelusta. Tutkittavat ohjeistettiin ottamaan nauhoitus kahdelta työ- ja yhdeltä vapaapäivältä. Liikunta-aktiivisuuden määrää kuvattiin liikunnan useuden, keston ja rasittavuuden perusteella lasketulla MET-arvolla (MET tuntia/päivä) lukuun ottamatta suurta Firstbeat Technologies Oy:lta käyttöön saatua aineistoa, jossa liikunta-aktiivisuuden arvio perustui sykevälinauhoitukseen ja sen pohjalta arvioituun hapenkulutukseen. Fyysisen kunnon arvio perustui laboratoriossa juoksumatolla suoritettuun sub-maksimaaliseen kuntotestiin. Kehonkoostumuksen arvioinnissa käytettiin kehon painon ja pituuden perusteella laskettavaa kehon painoindeksiä (kg/m^2) sekä kehon rasvaprosenttia.

Tulokset osoittivat, että objektiivisesti mitattu sykevälivaihteluun pohjautuva stressi oli yhteydessä subjektiiviseen stressiin. Seurannassa havaittiin keskimääräinen sekä yksilötasolla tapahtuva lasku subjektiivisessa stressitasossa. Objektiivisesti mitatun stressin/palautumisen tasoissa ei tapahtunut muutosta. Matala objektiivisesti mitattu stressireaktioiden voimakkuuden ja korkea palautumisreaktioiden voimakkuuden taso olivat yhteydessä voimakkaampaan subjektiivisen stressin laskuun. Liikunta-aktiivisuus, hyvä fyysinen kunto ja terveyden kannalta edullinen kehonkoostumus olivat yhteydessä pienempään objektiivisesti mitatun stressin määrään työpäivänä. Hyvä fyysinen kunto ja terveydelle edullinen kehonkoostumus olivat yhteydessä matalaan stressireaktioiden voimakkuuteen työpäivän aikana sekä parempaan työpäivän jälkeisen yön palautumiseen. Seurannassa havaittiin keskimääräistä korkeamman liikunta-aktiivisuuden tason olevan yhteydessä keskimääräistä voimakkaampaan subjektiivisen stressin laskuun.

Tämän tutkimuksen tulosten perusteella voidaan päätellä, että liikunta-aktiivisuudella on merkitystä stressinhallinnassa. Hyvä fyysinen kunto ja terveydelle edullinen kehonkoostumus vaikuttaisivat olevan tärkeitä hyvälle työpäivän jälkeiselle palautumiselle. Tulokset tukevat sykevälivaihteluun pohjautuvan menetelmän käytettävyyttä stressin arvioinnissa subjektiivisten menetelmien rinnalla. Tuloksia voidaan hyödyntää monin tavoin terveyspolitiikassa, työpaikoilla sekä terveysalan ammattilaisten päivittäisessä kliinisessä työssä.

REFERENCES

Abbas, S. G., Farah, A. & Apkinar-Sposito, C. 2013. Measuring the immeasurable! An overview of stress & strain measuring instruments. Mediterranean Journal of Social Sciences 4 (10), 480-489. doi:10.5901/mjss.2013.v4n10p480.

Ainsworth, B. E., Haskell, W. L., Herrmann, S. D., Meckes, N., Bassett, D. R.,Jr, Tudor-Locke, C., Greer, J. L., Vezina, J., Whitt-Glover, M. C. & Leon, A. S. 2011. 2011 Compendium of Physical Activities: a second update of codes and MET values. Medicine and Science in Sports and Exercise 43 (8), 1575-1581.

Andersen, K., Shephard, R., Denolin, H., Varnauskas, E. & Masironi, R. 1971. Fundamentals of Exercise Testing. Geneva: World Health Organization.

Andreoli, A., Scalzo, G., Masala, S., Tarantino, U. & Guglielmi, G. 2009. Body composition assessment by dual-energy X-ray absorptiometry (DXA). La Radiologia Medica 114 (2), 286-300.

Arena, R., Myers, J., Williams, M. A., Gulati, M., Kligfield, P., Balady, G. J., Collins, E. & Fletcher, G. 2007. Assessment of Functional Capacity in Clinical and Research Settings A Scientific Statement From the American Heart Association Committee on Exercise, Rehabilitation, and Prevention of the Council on Clinical Cardiology and the Council on Cardiovascular Nursing. Circulation 116 (3), 329-343.

Armon, G., Shirom, A., Berliner, S., Shapira, I. & Melamed, S. 2008. A prospective study of the association between obesity and burnout among apparently healthy men and women. Journal of Occupational Health Psychology 13 (1), 43-57.

Asztalos, M., Huybrechts, I., Temme, E., Van Oyen, H. & Vandevijvere, S. 2013. Association of physical activity, waist circumference and body mass index with subjective health among Belgian adults. European Journal of Public Health 24 (2), 205-209.

Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J. & Martin, B. W. Lancet Physical Activity Series Working Group 2012. Correlates of physical activity: why are some people physically active and others not? The Lancet 380 (9838), 258-271.

Bhui, K. S., Dinos, S., Stansfeld, S. A. & White, P. D. 2012. A synthesis of the evidence for managing stress at work: a review of the reviews reporting on anxiety, depression, and absenteeism. Journal of Environmental and Public Health. doi:10.1155/2012/515874.

Billman, G. E. 2011. Heart rate variability–a historical perspective. Frontiers in Physiology 2 (86). doi: 10.3389/fphys.2011.00086.

Birdee, G. S., Byrne, D. W., McGown, P. W., Rothman, R. L., Rolando, L. A., Holmes, M. C. & Yarbrough, M. I. 2013. Relationship between physical inactivity and health characteristics among participants in an employee-wellness program. Journal of Occupational and Environmental Medicine 55 (5), 514-519.

Blair, S. N., Cheng, Y. & Holder, J. S. 2001. Is physical activity or physical fitness more important in defining health benefits? Medicine and Science in Sports and Exercise 33 (6), S379-S399.

Block, J. P., He, Y., Zaslavsky, A. M., Ding, L. & Ayanian, J. Z. 2009. Psychosocial stress and change in weight among US adults. American Journal of Epidemiology 170 (2), 181-192.

Bollen, K.A., & Curran, P.J. 2006. Latent Curve Models: A Structural Equation Perspective. New Jersey, United States of America: John Wiley & Sons.

Booth, F. W., Roberts, C. K. & Laye, M. J. 2012. Lack of exercise is a major cause of chronic diseases. Comprehensive Physiology 2 (2), 1143-1211.

Bouchard, C., Blair, S. N. & Haskell, W. L. 2007. Why study physical activity and health? In Bouchard, C., Blair, S.N. & Haskell W.L. (editors) Physical activity and Health. Champaign, United States of America: Human Kinetics, 3-19.

Branca, F., Nikogosian, H. & Lobstein, T. 2007. The challenge of obesity in the WHO European Region and the strategies for response: Summary. Denmark: World Health Organization.

Bravata, D. M., Smith-Spangler, C., Sundaram, V., Gienger, A. L., Lin, N., Lewis, R., Stave, C. D., Olkin, I. & Sirard, J. R. 2007. Using pedometers to increase physical activity and improve health: a systematic review. JAMA 298 (19), 2296-2304.

Bray, G. A. 2004. Medical consequences of obesity. The Journal of Clinical Endocrinology & Metabolism 89 (6), 2583-2589.

Brotman, D. J., Golden, S. H. & Wittstein, I. S. 2007. The cardiovascular toll of stress. The Lancet 370 (9592), 1089-1100.

Campbell, J. & Ehlert, U. 2012. Acute psychosocial stress: does the emotional stress response correspond with physiological responses? Psychoneuroendocrinology 37 (8), 1111-1134.

Cannon, W. B. 1932. The wisdom of the body. New York, United States of America: W W Norton & Company.

Caspersen, C. J., Powell, K. E. & Christenson, G. M. 1985. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Reports 100 (2), 126-131.

Chandola, T., Britton, A., Brunner, E., Hemingway, H., Malik, M., Kumari, M., Badrick, E., Kivimäki, M. & Marmot, M. 2008. Work stress and coronary heart disease: what are the mechanisms? European Heart Journal 29 (5), 640-648.

Chandola, T., Heraclides, A. & Kumari, M. 2010. Psychophysiological biomarkers of workplace stressors. Neuroscience & Biobehavioral Reviews 35 (1), 51-57.

Cheema, B. S., Houridis, A., Busch, L., Raschke-Cheema, V., Melville, G. W., Marshall, P. W., Chang, D., Machliss, B., Lonsdale, C., Bowman, J. & Colagiuri, B. 2013. Effect of an office worksite-based yoga program on heart rate variability: outcomes of a randomized controlled trial. BMC Complementary and Alternative Medicine 13 (82). doi:10.1186/1472-6882.

Clays, E., De Bacquer, D., Crasset, V., Kittel, F., De Smet, P., Kornitzer, M., Karasek, R. & De Backer, G. 2011. The perception of work stressors is related to reduced parasympathetic activity. International Archives of Occupational and Environmental Health 84 (2), 185-191.

Cohen, S., Kamarck, T. & Mermelstein, R. 1983. A global measure of perceived stress. Journal of Health and Social Behavior, 385-396.

Cohen, S., Kessler, R. C. & Gordon, L. U. 1995. Strategies for measuring stress in studies of psychiatric and physical disorders. In Cohen, S., Kessler, R. C. & Gordon, L. U. (editors) Measuring stress: A guide for health and social scientists. New York, United States of America: Oxford University Press, 3-26.

Collins, S. M., Karasek, R. A. & Costas, K. 2005. Job strain and autonomic indices of cardiovascular disease risk. American Journal of Industrial Medicine 48 (3), 182-193.

Collins, S. & Karasek, R. 2010. Reduced vagal cardiac control variance in exhausted and high strain job subjects. International Journal of Occupational Medicine and Environmental Health 23 (3), 267-278.

Conn, V. S., Hafdahl, A. R., Cooper, P. S., Brown, L. M. & Lusk, S. L. 2009. Meta-analysis of workplace physical activity interventions. American Journal of Preventive Medicine 37 (4), 330-339.

Cordes, C. L. & Dougherty, T. W. 1993. A review and an integration of research on job burnout. Academy of Management Review 18 (4), 621-656.

De Jong, M. & Randall, D. C. 2005. Heart rate variability analysis in the assessment of autonomic function in heart failure. Journal of Cardiovascular Nursing 20 (3), 186-195.

De Vriendt, T., Moreno, L. A. & De Henauw, S. 2009. Chronic stress and obesity in adolescents: scientific evidence and methodological issues for epidemiological research. Nutrition, Metabolism and Cardiovascular Diseases 19 (7), 511-519.

Denver, J. W., Reed, S. F. & Porges, S. W. 2007. Methodological issues in the quantification of respiratory sinus arrhythmia. Biological Psychology 74 (2), 286-294.

Deurenberg, P., Deurenberg-Yap, M. & Guricci, S. 2002. Asians are different from Caucasians and from each other in their body mass index/body fat per cent relationship. Obesity Reviews 3 (3), 141-146.

Di Pietro, L., Dziura, J. & Blair, S. N. 2004. Estimated change in physical activity level (PAL) and prediction of 5-year weight change in men: the Aerobics Center Longitudinal Study. International Journal of Obesity 28 (12), 1541-1547.

Dodge, R., Daly, A. P., Huyton, J. & Sanders, L. D. 2012. The challenge of defining wellbeing. International Journal of Wellbeing 2 (3), 222-235.

Driver, H. S. & Taylor, S. R. 2000. Exercise and sleep. Sleep Medicine Reviews 4 (4), 387-402.

Ekkekakis, P. & Petruzzello, S. J. 1999. Acute aerobic exercise and affect: current status, problems and prospects regarding dose-response. Sports Medicine 28 (5), 337-347.

Eller, N. H., Blønd, M., Nielsen, M., Kristiansen, J. & Netterstrøm, B. 2011. Effort reward imbalance is associated with vagal withdrawal in Danish public sector employees. International Journal of Psychophysiology 81 (3), 218-224.

Firstbeat Technologies Ltd. 2014. White papers. [Access date March 8th, 2016] Available online at: http://www.firstbeat.com/physiology/white-papers

Fitchett, M. A. 1985. Predictability of VO2 max from submaximal cycle ergometer and bench stepping tests. British Journal of Sports Medicine 19 (2), 85-88.

Forcier, K., Stroud, L. R., Papandonatos, G. D., Hitsman, B., Reiches, M., Krishnamoorthy, J. & Niaura, R. 2006. Links between physical fitness and cardiovascular reactivity and recovery to psychological stressors: A meta-analysis. Health Psychology 25 (6), 723-739.

Foss, B. & Dyrstad, S. M. 2011. Stress in obesity: cause or consequence? Medical Hypotheses 77 (1), 7-10.

Furlan, R., Guzzetti, S., Crivellaro, W., Dassi, S., Tinelli, M., Baselli, G., Cerutti, S., Lombardi, F., Pagani, M. & Malliani, A. 1990. Continuous 24-hour assessment of the neural regulation of systemic arterial pressure and RR variabilities in mbulant subjects. Circulation 81 (2), 537-547.

Furlan, R., Piazza, S., Dell ’Orto, S., Gentile, E., Cerutti, S., Pagani, M. & Malliani, A. 1993. Early and late effects of exercise and athletic training on neural mechanisms controlling heart rate. Cardiovascular Research 27, 482–488.

Gao, Y. Y., Lovejoy, J. C., Sparti, A., Bray, G. A., Keys, L. K. & Partington, C. 1996. Autonomic activity assessed by heart rate spectral analysis varies with fat distribution in obese women. Obesity Research 4 (1), 55-63.

Garber C. E., Blissmer B., Deschenes M. R., Franklin B. A., Lamonte M. J., Lee I. M., Nieman D. C. & Swain D. P. 2011. American College of Sports Medicine Position Stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. Medicine and Science in Sports and Exercise 43 (7), 1334-1359.

Garrow, J. S. & Webster, J. 1985. Quetelet's index (W/H2) as a measure of fatness. International Journal of Obesity 9 (2), 147-153.

Gerber, M. & Pühse, U. 2009. Review Article: Do exercise and fitness protect against stress-induced health complaints? A review of the literature. Scandinavian Journal of Public Health 37 (8), 801-819.

Geurts, S. A. & Sonnentag, S. 2006. Recovery as an explanatory mechanism in the relation between acute stress reactions and chronic health impairment. Scandinavian Journal of Work, Environment & Health 32, 482-492.

Goodwin, R. D. 2003. Association between physical activity and mental disorders among adults in the United States. Preventive Medicine 36 (6), 698-703.

Grassi, G., Dell'Oro, R., Facchini, A., Trevano, F. Q., Bolla, G. B. & Mancia, G. 2004. Effect of central and peripheral body fat distribution on sympathetic and baroreflex function in obese normotensives. Journal of Hypertension 22 (12), 2363-2369.

Grossman, A., Bouloux, P., Price, P., Drury, P., Lam, K., Turner, T., Thomas, J., Besser, G. & Sutton, J. 1984. The role of opioid peptides in the hormonal responses to acute exercise in man. Clinical Science 67 (5), 483-491.

Grossman, P. & Taylor, E. W. 2007. Toward understanding respiratory sinus arrhythmia: relations to cardiac vagal tone, evolution and biobehavioral functions. Biological Psychology 74 (2), 263-285.

Hales, S. 1733. Statistical Essays: Concerning Haemastaticks; or, an Account of some Hydraulick and Hydrostatical Experiments made on the Blood and Blood-Vessels of Animals. London, United Kingdom: W. Innys and R. Manby.

Hall, M., Vasko, R., Buysse, D., Ombao, H., Chen, Q., Cashmere, J. D., Kupfer, D. & Thayer, J. F. 2004. Acute stress affects heart rate variability during sleep. Psychosomatic Medicine 66 (1), 56-62.

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., Ekelund, U. & Lancet Physical Activity Series Working Group 2012. Global physical activity levels: surveillance progress, pitfalls, and prospects. The Lancet 380 (9838), 247-257.

Hamer, M. 2012. Psychosocial Stress and Cardiovascular Disease Risk: The Role of Physical Activity. Psychosomatic Medicine 74 (9), 896-903.

Hamer, M. & Stamatakis, E. 2010. Objectively assessed physical activity, fitness and subjective wellbeing. Mental Health and Physical Activity 3 (2), 67-71.

Hansen, B. H., Holme, I., Anderssen, S. A. & Kolle, E. 2013. Patterns of objectively measured physical activity in normal weight, overweight, and obese individuals (20–85 years): a cross-sectional study. PLoS ONE 8 (1), e53044. doi:10.1371/journal.pone.0053044.

Hanson, E., Godaert, G., Maas, C. & Meijman, T. 2001. Vagal cardiac control throughout the day: the relative importance of effort–reward imbalance and within-day measurements of mood, demand and satisfaction. Biological Psychology 56 (1), 23-44.

Hautala, A., Tulppo, M. P., Mäkikallio, T. H., Laukkanen, R., Nissilä, S. & Huikuri, H. V. 2001. Changes in cardiac autonomic regulation after prolonged maximal exercise. Clinical Physiology 21 (2), 238–245.

Hautala, A., Martinmäki, K., Kiviniemi, A., Kinnunen, H., Virtanen, P., Jaatinen, J., & Tulppo, M. 2012. Effects of habitual physical activity on response to endurance training. Journal of Sports Sciences 30(6), 563-569.

Hegberg, N. J. & Tone, E. B. 2015. Physical activity and stress resilience: Considering those at-risk for developing mental health problems. Mental Health and Physical Activity 8, 1-7.

Helldán, A. & Helakorpi, S. 2015. Suomalaisen aikuisväestön terveyskäyttäytyminen ja terveys, kevät 2014 -Health Behaviour and Health among the Finnish Adult Population, Spring 2014. [Access date April 11th, 2016] Available online at: http://www.julkari.fi/handle/10024/126023

Hirvonen, N., Huotari, M., Niemelä, R. & Korpelainen, R. 2012. Information behavior in stages of exercise behavior change. Journal of the American Society for Information Science and Technology 63 (9), 1804-1819.

Howley, E. T. 2001. Type of activity: resistance, aerobic and leisure versus occupational physical activity. Medicine and Science in Sports and Exercise 33 (6), 364-369.

Hu, L. & Bentler, P. M. 1999. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. Structural Equation Modeling: a Multidisciplinary Journal 6 (1), 1-55.

Husu, P., Suni, J., Vähä-Ypyä, H., Sievänen, H., Tokola, K., Valkeinen, H., Mäki-Opas, T. & Vasankari, T. 2014. Suomalaisten aikuisten kiihtyvyysmittarilla mitattu fyysinen aktiivisuus ja liikkumattomuus. Suomen Lääkärilehti 25 (32), 1860-1866.

Hynynen, E., Vesterinen, V., Nummela, A. & Rusko, H. 2010. Effects of moderate and heavy endurance exercise on nocturnal HRV. International Journal of Sports Medicine 31, 428–432.

Hynynen, E., Konttinen, N., Kinnunen, U., Kyröläinen, H. & Rusko, H. 2011. The incidence of stress symptoms and heart rate variability during sleep and orthostatic test. European Journal of Applied Physiology 111 (5), 733-741.

Isowa, T., Ohira, H. & Murashima, S. 2006. Immune, endocrine and cardiovascular responses to controllable and uncontrollable acute stress. Biological Psychology 71 (2), 202-213.

Jang, T., Kim, H., Lee, H., Myong, J. & Koo, J. 2013. Long work hours and obesity in Korean adult workers. Journal of Occupational Health 55 (5), 359-366.

Jarczok, M. N., Jarczok, M., Mauss, D., Koenig, J., Li, J., Herr, R. M. & Thayer, J. F. 2013. Autonomic nervous system activity and workplace stressors—A systematic review. Neuroscience & Biobehavioral Reviews 37 (8), 1810-1823.

Jarczok, M. N., Kleber, M. E., Koenig, J., Loerbroks, A., Herr, R. M., Hoffmann, K., Fischer, J. E., Benyamini, Y. & Thayer, J. F. 2015. Investigating the associations of self-rated health: heart rate variability is more strongly associated than inflammatory and other frequently used biomarkers in a cross sectional occupational sample. PloS ONE 10 (2), e0117196. doi: 10.1371/journal.pone.0117196.

Jarczok, M. N., Koenig, J., Li, J., Mauss, D., Hoffmann, K., Schmidt, B., Fischer, J. E. & Thayer, J. F. 2016. The Association of Work Stress and Glycemic Status Is Partially Mediated by Autonomic Nervous System Function: Cross-Sectional Results from the Mannheim Industrial Cohort Study (MICS). PLoS One 11 (8), e0160743. doi: 10.1371/journal.pone.0160743.

Jonsdottir, I. H., Rödjer, L., Hadzibajramovic, E., Börjesson, M. & Ahlborg, G. 2010. A prospective study of leisure-time physical activity and mental health in Swedish health care workers and social insurance officers. Preventive Medicine 51 (5), 373-377.

Jose, A.D. & Collison, D. 1970. The normal range and determinants of the intrinsic heart rate in man. Cardiovascular Research 4, 160–167.

Jurca, R., Church, T. S., Morss, G. M., Jordan, A. N. & Earnest, C. P. 2004. Eight weeks of moderate-intensity exercise training increases heart rate variability in sedentary postmenopausal women. American Heart Journal 147 (5). doi:10.1016/j.ahj.2003.10.024.

Kaikkonen, P., Rusko, H. & Martinmäki, K. 2008. Post-exercise heart rate variability of endurance athletes after different high-intensity exercise interventions. Scandinavian Journal of Medicine & Science in Sports 18 (4), 511-519.

Karakaya, O., Barutcu, I., Kaya, D., Esen, A. M., Saglam, M., Melek, M., Onrat, E., Turkmen, M., Esen, O. B. & Kaymaz, C. 2007. Acute effect of cigarette smoking on heart rate variability. Angiology 58 (5), 620-624.

Karasek, R. A. 1979. Job demands, job decision latitude, and mental strain: Implications for job redesign. Administrative Science Quarterly 24 (2), 285-308.

Karason, K., Mølgaard, H., Wikstrand, J. & Sjöström, L. 1999. Heart rate variability in obesity and the effect of weight loss. The American Journal of Cardiology 83 (8), 1242-1247.

Katzmarzyk, P., Craig, C. & Gauvin, L. 2007. Adiposity, physical fitness and incident diabetes: the physical activity longitudinal study. Diabetologia 50 (3), 538-544.

Kettunen, J. & Saalasti, S., inventors; Firstbeat Technologies Ltd., assignee. 2005. Procedure for deriving reliable information on respiratory activity from heart period measurement. United States patent US 20050209521A1.

Kettunen, J. & Saalasti, S., inventors; Firstbeat Technologies Ltd., assignee. 2008. Procedure for detection of stress by segmentation and analyzing heart beat signal. United States patent US 007330752B2.

Kim, J. A., Park, Y., Cho, K., Hong, M., Han, H., Choi, Y. & Yoon, D. 2005. Heart rate variability and obesity indices: emphasis on the response to noise and standing. The Journal of the American Board of Family Practice 18 (2), 97-103.

Kinnunen, M. 2005. Allostatic load in relation to psychosocial stressors and health. PhD Thesis. University of Jyväskylä, Finland: University of Jyväskylä.

Kirk, M. A. & Rhodes, R. E. 2011. Occupation correlates of adults' participation in leisure-time physical activity: a systematic review. American Journal of Preventive Medicine 40 (4), 476-485.

Kivimäki, M., Leino-Arjas, P., Kaila-Kangas, L., Luukkonen, R., Vahtera, J., Elovainio, M., Harma, M. & Kirjonen, J. 2006. Is incomplete recovery from work a risk marker of cardiovascular death? Prospective evidence from industrial employees. Psychosomatic Medicine 68 (3), 402-407.

Klaperski, S., von Dawans, B., Heinrichs, M. & Fuchs, R. 2013. Does the level of physical exercise affect physiological and psychological responses to psychosocial stress in women? Psychology of Sport and Exercise 14 (2), 266-274.

Koenig, J., Jarczok, M., Warth, M., Ellis, R., Bach, C., Hillecke, T. & Thayer, J. F. 2014. Body mass index is related to autonomic nervous system activity as measured by heart rate variability—A replication using short term measurements. The Journal of Nutrition, Health & Aging 18 (3), 300-302.

Kompier, M. 2005. Assessing the psychosocial work environment—" subjective" versus" objective" measurement. Scandinavian Journal of Work, Environment & Health 31(6), 405-408.

Kouvonen, A., Vahtera, J., Oksanen, T., Pentti, J., Väänänen, A. K., Heponiemi, T., Salo, P., Virtanen, M. & Kivimäki, M. 2013. Chronic workplace stress and insufficient physical activity: a cohort study. Occupational and Environmental Medicine 70 (1), 3-8.

Kujala, U. M., Kaprio, J., Sarna, S. & Koskenvuo, M. 1998. Relationship of leisure-time physical activity and mortality: the Finnish twin cohort. JAMA 279 (6), 440-444.

Kujala, U. M. 2009. Evidence on the effects of exercise therapy in the treatment of chronic disease. British Journal of Sports Medicine 43 (8), 550-555.

Kujala, U. M., Mäkinen, V. P., Heinonen, I., Soininen, P., Kangas, A. J., Leskinen, T. H., Rahkila, P., Wurtz, P., Kovanen, V., Cheng, S., Sipilä, S., Hirvensalo, M., Telama, R., Tammelin, T., Savolainen, M. J., Pouta, A., O'Reilly, P. F., Mäntyselkä, P., Viikari, J., Kähönen, M., Lehtimäki, T., Elliott, P., Vanhala, M. J., Raitakari, O. T., Järvelin, M. R., Kaprio, J., Kainulainen, H. & Ala-Korpela, M. 2013. Long-term leisure-time physical activity and serum metabolome. Circulation 127 (3), 340-348.

Lallukka, T., Sarlio-Lähteenkorva, S., Kaila-Kangas, L., Pitkäniemi, J., Luukkonen, R. & Leino-Arjas, P. 2008. Working conditions and weight gain: a 28-year follow-up study of industrial employees. European Journal of Epidemiology 23 (4), 303-310.

Lappalainen, R., Sairanen, E., Järvelä, E., Rantala, S., Korpela, R., Puttonen, S., Kujala, U. M., Myllymäki, T., Peuhkuri, K. & Mattila, E. 2014. The effectiveness and applicability of different lifestyle interventions for enhancing wellbeing: the study design for a randomized controlled trial for persons with metabolic syndrome risk factors and psychological distress. BMC Public Health 14, 310. doi:10.1186/1471-2458-14-310.

Lazarus, R. S., & Folkman, S. 1984. Stress, appraisal, and coping. New York: Springer.

Loerbroks, A., Schilling, O., Haxsen, V., Jarczok, M. N., Thayer, J. F. & Fischer, J. E. 2010. The fruits of ones labor: Effort–reward imbalance but not job strain is related to heart rate variability across the day in 35–44-year-old workers. Journal of Psychosomatic Research 69 (2), 151-159.

Lundberg, U. 2005. Stress hormones in health and illness: the roles of work and gender. Psychoneuroendocrinology 30 (10), 1017-1021.

Makowska, Z., Merecz, D., Moscicka, A. & Kolasa, W. 2002. The validity of general health questionnaires, GHQ-12 and GHQ-28, in mental health studies of working people. International Journal of Occupational Medicine and Environmental Health 15 (4), 353-362.

Malik, M. & Camm, A. J. 1993. Components of heart rate variability—what they really mean and what we really measure. The American Journal of Cardiology 72 (11), 821-822.

Malliani, A., Pagani, M., Lombardi, F. & Cerutti, S. 1991. Cardiovascular neural regulation explored in the frequency domain. Circulation 84 (2), 482-492.

Martinmäki, K., Rusko, H., Saalasti, S. & Kettunen, J. 2006a. Ability of short-time Fourier transform method to detect transient changes in vagal effects on hearts: a pharmacological blocking study. American Journal of Physiology-Heart and Circulatory Physiology 290 (6), H2582–H2589.

Martinmäki, K., Rusko, H., Kooistra, L., Kettunen, J. & Saalasti, S. 2006b. Intraindividual validation of heart rate variability indexes to measure vagal effects on hearts. American Journal of Physiology-Heart and Circulatory Physiology 290 (2), H640-H647.

Maslach, C., Schaufeli, W. B. & Leiter, M. P. 2001. Job burnout. Annual Review of Psychology 52 (1), 397-422.

Maule, S., Rabbia, F., Perni, V., Tosello, F., Bisbocci, D., Mulatero, P. & Veglio, F. 2008. Prolonged QT interval and reduced heart rate variability in patients with uncomplicated essential hypertension. Hypertension Research 31 (11), 2003-2010.

McArdle, W. D., Katch, F. I. & Katch, V. L. 2010. Exercise physiology – nutrition, energy, and human performance. 7th edition. Baltimore, United States of America: Lippincott Williams & Wilkins.

McEwen, B. S. 2000. Allostasis and allostatic load: implications for neuropsychopharmacology. Neuropsychopharmacology 22 (2), 108-124.

McLaren, L. 2007. Socioeconomic status and obesity. Epidemiologic reviews 29 (1), 29-48.

McMillan, D. E. 2002. Interpreting heart rate variability sleep/wake patterns in cardiac patients. Journal of Cardiovascular Nursing 17 (1), 69-81.

Meijman, T. F. & Mulder, G. 1998. Psychological aspects of workload. In Drenth, J. D., Thierry, H. & de Wolf, C. J. (editors) Handbook of work and organizational psychology: Work psychology. 2nd edition. Hove, United Kingdom: Psychology Press Ltd., 5-33.

Melanson, E. L. J., Freedson, P. S. & Blair, S. 1996. Physical activity assessment: a review of methods. Critical Reviews in Food Science & Nutrition 36 (5), 385-396.

Melville, G. W., Chang, D., Colagiuri, B., Marshall, P. W. & Cheema, B. S. 2012. Fifteen minutes of chair-based yoga postures or guided meditation performed in the office can elicit a relaxation response. Evidence-based Complementary and Alternative Medicine. doi:10.1155/2012/501986.

Millis, R. M., Austin, R. E., Hatcher, M. D., Bond, V., Faruque, M. U., Goring, K. L., Hickey, B. M. & DeMeersman, R. E. 2010. Association of body fat percentage and heart rate variability measures of sympathovagal balance. Life Sciences 86 (5), 153-157.

Molfino, A., Fiorentini, A., Tubani, L., Martuscelli, M., Fanelli, F. R. & Laviano, A. 2009. Body mass index is related to autonomic nervous system activity as measured by heart rate variability. European Journal of Clinical Nutrition 63 (10), 1263-1265.

Montano, N., Porta, A., Cogliati, C., Costantino, G., Tobaldini, E., Casali, K. R. & Iellamo, F. 2009. Heart rate variability explored in the frequency domain: a tool to investigate the link between heart and behavior. Neuroscience & Biobehavioral Reviews 33 (2), 71-80.

Morgan, W. P. 1985. Affective beneficence of vigorous physical activity. Medicine & Science in Sports & Exercise 17 (1), 94-100.

Muthén, L. K. & Muthén, B. O. 1998-2012. Mplus User's Guide. 7th edition. Los Angeles, United States of America: Muthén & Muthén.

Mutikainen, S., Helander, E., Pietilä, J., Korhonen, I. & Kujala, U. M. 2014. Objectively measured physical activity in Finnish employees: a cross-sectional study. BMJ open 4 (12), e005927-2014-005927. doi:10.1136/bmjopen-2014-005927.

Myers, J., Kaykha, A., George, S., Abella, J., Zaheer, N., Lear, S., Yamazaki, T. & Froelicher, V. 2004. Fitness versus physical activity patterns in predicting mortality in men. The American Journal of Medicine 117 (12), 912-918.

Myllymäki, T., Kyröläinen, H., Savolainen, K., Hokka, L., Jakonen, R., Juuti, T., Martinmäki, K., Kaartinen, J., Kinnunen, M. & Rusko, H. 2011. Effects of vigorous late-night exercise on sleep quality and cardiac autonomic activity. Journal of Sleep Research 20, 146-153.

Mäkikallio, T. H., Seppänen, T., Niemelä, M., Airaksinen, K. E. J., Tulppo, M., Huikuri, H. V. 1996. Abnormalities in beat to beat complexity of heart rate dynamics in patients with a previous myocardial infarction. Journal of the American College of Cardiology 28 (4), 1005-1011.

Näätänen, P., Aro, A., Matthiesen, S. & Salmela-Aro, K. 2003. Bergen burnout indicator 15. Helsinki, Finland: Edita.

North, T., McCullagh, P. & Tran, Z. 1990. Effect of exercise on depression. Exercise and Sport Sciences Reviews 18 (1), 379-416.

Nyberg, S. T., Heikkilä, K., Fransson, E. I., Alfredsson, L., De Bacquer, D., Bjorner, J. B., Bonenfant, S., Borritz, M., Burr, H., Casini, A. C., E., Dragano, N., Erbel, R., Geuskens, G. A., Goldberg, M., Hooftman, W. E., Houtman, I. L., Jockel, K. H., Kittel, F., Knutsson, A., Koskenvuo, M., Leineweber, C., Lunau, T., Madsen, I. E., Hanson, L. L., Marmot, M. G., Nielsen, M. L., Nordin, M., Oksanen, T., Pentti, J., Rugulies, R., Siegrist, J., Suominen, S., Vahtera, J., Virtanen, M., Westerholm, P., Westerlund, H., Zins, M., Ferrie, J. E., Theorell, T., Steptoe, A., Hamer, M., Singh-Manoux, A., Batty, G. D. & Kivimäki, M. I. C. 2012. Job strain in relation to body mass index: pooled analysis of 160 000 adults from 13 cohort studies. Journal of Internal Medicine 272 (1), 65-73.

Orizio, C., Perini, R., Comande, A., Castellano, M., Beschi, M. & Veicsteinas, A. 1988. Plasma catecholamines and heart rate at the beginning of muscular exercise in man. European Journal of Applied Physiology & Occupational Physiology 57 (5), 644-651.

Osborne, J. W. 2010. Improving your data transformations: Applying the Box-Cox transformation. Practical Assessment, Research & Evaluation 15 (12), 1-9.

Overgaard, D., Gyntelberg, F. & Heitmann, B. 2004. Psychological workload and body weight: is there an association? A review of the literature. Occupational Medicine 54 (1), 35-41.

Pärkkä, J., Merilahti, J., Mattila, E. M., Malm, E., Antila, K., Tuomisto, M. T., Saarinen, A. V., van Gils, M. & Korhonen, I. 2009. Relationship of psychological and physiological variables in long-term self-monitored data during work ability rehabilitation program. IEEE Transactions on Information Technology in Biomedicine 13 (2), 141-151.

Pate, R. R., O'Neill, J. R. & Lobelo, F. 2008. The evolving definition of "sedentary". Exercise and Sport Sciences Reviews 36 (4), 173-178.

Pedersen, B. K. & Saltin, B. 2006. Evidence for prescribing exercise as therapy in chronic disease. Scandinavian Journal of Medicine & Science in Sports 16 (1), 3-63.

Philipson, T. J. & Posner, R. A. 2003. The long-run growth in obesity as a function of technological change. Perspectives in Biology and Medicine 46 (3), 87-108.

Physical Activity Guidelines Advisory Committee 2008. Physical Activity Guidelines Advisory Committee Report, 2008. Washington DC, United States of America: Department of Health and Human Services.

Pichot, V., Roche, F., Denis, C., Garet, M., Duverney, D., Costes, F. & Barthélémy, J. 2005. Interval training in elderly men increases both heart rate variability and baroreflex activity. Clinical Autonomic Research 15 (2), 107-115.

Pinquart, M. 2001. Correlates of subjective health in older adults: a meta-analysis. Psychology and Aging 16 (3), 414-426.

Pischon, T., Boeing, H., Hoffmann, K., Bergmann, M., Schulze, M., Overvad, K., Van Der Schouw, Y., Spencer, E., Moons, K. & Tjønneland, A. 2008. General and abdominal adiposity and risk of death in Europe. New England Journal of Medicine 359 (20), 2105-2120.

Pober, D. M., Braun, B. & Freedson, P. S. 2004. Effects of a single bout of exercise on resting heart rate variability. Medicine and Science in Sports and Exercise 36 (7), 1140-1148.

Porges, S. W. 1992. Vagal tone: a physiologic marker of stress vulnerability. Pediatrics 90 (3), 498-504.

Porges, S. W. 1995. Cardiac vagal tone: a physiological index of stress. Neuroscience & Biobehavioral Reviews 19 (2), 225-233.

Prince, S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Connor Gorber, S. & Tremblay, M. 2008. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. The International Journal of Behavioral Nutrition and Physical activity 5, 56. doi: 10.1186/1479-5868-5-56.

Proper, K. I., Koppes, L. L. J., van Zwieten, M. H. J. & Bemelmans, W. J. E. 2012. The prevalence of chronic psychological complaints and emotional exhaustion among overweight and obese workers. International Archives of Occupational and Environmental Health 85 (5), 537-545.

Qi, L. & Cho, Y. A. 2008. Gene-environment interaction and obesity. Nutrition Reviews 66 (12), 684-694.

Raglin, J. S. & Morgan, W. P. 1985. Influence of vigorous exercise on mood state. The Behavior Therapist 8 (9), 179-183.

Reiner, M., Niermann, C., Jekauc, D. & Woll, A. 2013. Long-term health benefits of physical activity--a systematic review of longitudinal studies. BMC Public Health 13, 813. doi: 10.1186/1471-2458-13-813.

Rennie, K. L., Hemingway, H., Kumari, M., Brunner, E., Malik, M. & Marmot, M. 2003. Effects of moderate and vigorous physical activity on heart rate variability in a British study of civil servants. American Journal of Epidemiology 158 (2), 135-143.

Rimmele, U., Seiler, R., Marti, B., Wirtz, P. H., Ehlert, U. & Heinrichs, M. 2009. The level of physical activity affects adrenal and cardiovascular reactivity to psychosocial stress. Psychoneuroendocrinology 34 (2), 190-198.

Rissanen, P., Franssila - Kallunki, A. & Rissanen, A. 2001. Cardiac parasympathetic activity is increased by weight loss in healthy obese women. Obesity Research 9 (10), 637-643.

Robinson, B. F., Epstein, S. E., Beiser, G. D. & Braunwald, E. 1966. Control of heart rate by the autonomic nervous system. Studies in man on the interrelation between baroreceptor mechanisms and exercise. Circulation Research 19 (2), 400-411.

Rosengård-Bärlund, M., Bernardi, L., Fagerudd, J., Mäntysaari, M., Björkesten, C. A., Lindholm, H., Forsblom, C., Waden, J., Groop, P. & FinnDiane Study Group 2009. Early autonomic dysfunction in type 1 diabetes: a reversible disorder? Diabetologia 52 (6), 1164-1172.

Rosmond, R. 2005. Role of stress in the pathogenesis of the metabolic syndrome. Psychoneuroendocrinology 30 (1), 1-10.

Rusko, H., Rönkä, T., Uusitalo, A., Kinnunen, U., Mauno, S., Feldt, T., Kinnunen, M., Martinmäki, K., Hirvonen, A. & Hyttinen, S. 2006. Stress and relaxation during sleep and awake time, and their associations with free salivary cortisol after awakening. Nordic Ergonomics Society congress. [Access date April 11th, 2016] Available online at: https://www.firstbeat.com/app/uploads/2015/10/rusko_et_al_nes_2006_congress.pdf

Saalasti, S. 2003. Neural Networks for Heart Rate Time Series Analysis. PhD Thesis. University of Jyväskylä, Finland: University of Jyväskylä.

Saalasti , S., Seppänen, M. & Kuusela, A. 2004. Artefact correction for heart beat interval data. Advanced Methods for Processing Bioelectrical Signals ProBisi Meeting. [Access date August 17th, 2016] Available online at: https://www.firstbeat.com/app/uploads/2015/10/saalasti_et_al_probisi_2004_congress.pdf

Sallis, J. F. & Saelens, B. E. 2000. Assessment of physical activity by self-report: status, limitations, and future directions. Research Quarterly for Exercise and Sport 71 (2), 1-14.

Salmon, P. 2001. Effects of physical exercise on anxiety, depression, and sensitivity to stress: a unifying theory. Clinical Psychology Review 21 (1), 33-61.

Samitz, G., Egger, M. & Zwahlen, M. 2011. Domains of physical activity and all-cause mortality: systematic review and dose-response meta-analysis of cohort studies. International Journal of Epidemiology 40 (5), 1382-1400.

Schmidt, B., Loerbroks, A., Herr, R. M., Wilson, M. G., Jarczok, M. N., Litaker, D., Mauss, D., Bosch, J. A. & Fischer, J. E. 2014. Associations between supportive leadership and employees self-rated health in an occupational sample. International Journal of Behavioral Medicine 21 (5), 750-756.

Schwarz, L. & Kindermann, W. 1992. Changes in β-endorphin levels in response to aerobic and anaerobic exercise. Sports Medicine 13 (1), 25-36.

Sedentary Behaviour Research Network. 2012. Letter to the editor: standardized use of the terms “sedentary” and “sedentary behaviours”. Applied Physiology, Nutrition, and Metabolism 37 (3), 540-542.

Seiler, S., Haugen, O. & Kuffel, E. 2007. Autonomic recovery after exercise in trained athletes: intensity and duration effects. Medicine and Science in Sports & Exercise 39 (8), 1366–1373.

Semmer, N. K., Grebner, S. & Elfering, A. 2003. Beyond self-report: Using observational, physiological, and situation-based measures in research on occupational stress. In Perrewe, P. L. & Ganster D. C. (editors) Emotional and Physiological Processes and Positive Intervention Strategies. Bingley, United Kingdom: Emerald Group Publishing Limited, 205-263.

Siegrist, J. 1996. Adverse health effects of high-effort/low-reward conditions. Journal of Occupational Health Psychology 1 (1), 27-41.

Silventoinen, K., Tatsuse, T., Martikainen, P., Rahkonen, O., Lahelma, E., Sekine, M. & Lallukka, T. 2013. Occupational class differences in body mass index and weight gain in Japan and Finland. Journal of Epidemiology 23 (6), 443-450.

Singh, J. P., Larson, M. G., O'Donnell, C. J., Tsuji, H., Evans, J. C. & Levy, D. 1999. Heritability of heart rate variability: the Framingham Heart Study. Circulation 99 (17), 2251-2254.

Skrapari, I., Tentolouris, N., Perrea, D., Bakoyiannis, C., Papazafiropoulou, A. & Katsilambros, N. 2007. Baroreflex sensitivity in obesity: relationship with cardiac autonomic nervous system activity. Obesity 15 (7), 1685-1693.

Smolander, J., Ajoviita, M., Juuti, T., Nummela, A. & Rusko, H. 2011. Estimating oxygen consumption from heart rate and heart rate variability without individual calibration. Clinical Physiology and Functional Imaging 31 (4), 266-271.

Soares-Miranda, L., Sattelmair, J., Chaves, P., Duncan, G., Siscovick, D. S., Stein, P. K., & Mozaffarian, D. 2014. Physical activity and heart rate variability in older adults: the Cardiovascular Health Study. Circulation 129 (21), 2100-2110.

Solovieva, S., Lallukka, T., Virtanen, M. & Viikari-Juntura, E. 2013. Psychosocial factors at work, long work hours, and obesity: a systematic review. Scandinavian Journal of Work, Environment & Health 39 (3), 241-258.

Sonnentag, S., & Fritz, C. 2007. The Recovery Experience Questionnaire: development and validation of a measure for assessing recuperation and unwinding from work. Journal of Occupational Health Psychology 12 (3), 204-221.

Sonnentag, S. & Jelden, S. 2009. Job stressors and the pursuit of sport activities: a day-level perspective. Journal of Occupational Health Psychology 14 (2), 165-181.

Steptoe, A., Feldman, P., Kunz, S., Owen, N., Willemsen, G. & Marmot, M. 2002. Stress responsivity and socioeconomic status. A mechanism for increased cardiovascular disease risk? European Heart Journal 23 (22), 1757-1763.

Strath, S. J., Kaminsky, L. A., Ainsworth, B. E., Ekelund, U., Freedson, P. S., Gary, R. A., Richardson, C. R., Smith, D. T. & Swartz, A. M. 2013. Guide to the assessment of physical activity: Clinical and research applications: A scientific statement from the American Heart Association. Circulation 128 (20), 2259-2279.

Ströhle, A., Höfler, M., Pfister, H., Müller, A., Hoyer, J., Wittchen, H. & Lieb, R. 2007. Physical activity and prevalence and incidence of mental disorders in adolescents and young adults. Psychological Medicine 37 (11), 1657-1666.

Sui, X., LaMonte, M. J., Laditka, J. N., Hardin, J. W., Chase, N., Hooker, S. P. & Blair, S. N. 2007. Cardiorespiratory fitness and adiposity as mortality predictors in older adults. JAMA 298 (21), 2507-2516.

Suija, K., Timonen, M., Suviola, M., Jokelainen, J., Järvelin, M. & Tammelin, T. 2013. The association between physical fitness and depressive symptoms among young adults: results of the Northern Finland 1966 birth cohort study. BMC Public Health 13, 535. doi: 10.1186/1471-2458-13-535.

Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996. Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Circulation 93 (5), 1043-1065.

Thayer, J. F., & Fischer, J. E. 2009. Heart rate variability, overnight urinary norepinephrine and C-reactive protein: evidence for the cholinergic anti-inflammatory pathway in healthy human adults. Journal of Internal Medicine 265 (4), 439-447.

Thayer, J. F., Yamamoto, S. S. & Brosschot, J. F. 2010. The relationship of autonomic imbalance, heart rate variability and cardiovascular disease risk factors. International Journal of Cardiology 141 (2), 122-131.

Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J. & Wager, T. D. 2012. A meta-analysis of heart rate variability and neuroimaging studies: implications for heart rate variability as a marker of stress and health. Neuroscience & Biobehavioral Reviews 36 (2), 747-756.

Thøgersen-Ntoumani, C., Loughren, E. A., Kinnafick, F., Taylor, I. M., Duda, J. L. & Fox, K. R. 2015. Changes in work affect in response to lunchtime walking in previously physically inactive employees: A randomized trial. Scandinavian Journal of Medicine & Science in Sports 25 (6), 778-787.

Throne, L. C., Bartholomew, J. B., Craig, J. & Farrar, R. P. 2000. Stress reactivity in fire fighters: an exercise intervention. International Journal of Stress Management 7 (4), 235-246.

Tonello, L., Rodrigues, F. B., Souza, J. W., Campbell, C. S., Leicht, A. S. & Boullosa, D. A. 2014. The role of physical activity and heart rate variability for the control of work related stress. Frontiers in Physiology 5, 31-39. doi: 10.3389/fphys.2013.00346.

Tudor-Locke, C., Burkett, L., Reis, J., Ainsworth, B., Macera, C. & Wilson, D. 2005. How many days of pedometer monitoring predict weekly physical activity in adults? Preventive Medicine 40 (3), 293-298.

Tudor-Locke, C. E. & Myers, A. M. 2001. Challenges and opportunities for measuring physical activity in sedentary adults. Sports Medicine 31 (2), 91-100.

Tulppo, M. P., Hautala, A. J., Mäkikallio, T. H., Laukkanen, R. T., Nissilä, S., Hughson, R. L. & Huikuri, H. V. 2003. Effects of aerobic training on heart rate dynamics in sedentary subjects. Journal of Applied Physiology 95 (1), 364-372.

Tulppo, M. P., Mäkikallio, T. H., Takala, T. E., Seppänen, T., Huikuri, H. V. 1996. Quantitative beat-to-beat analysis of heart rate dynamics during exercise. The American Journal of Physiology 271 (1), 244-252.

Umetani, K., Singer, D. H., McCraty, R. & Atkinson, M. 1998. Twenty-four hour time domain heart rate variability and heart rate: relations to age and gender over nine decades. Journal of the American College of Cardiology 31 (3), 593-601.

Uusitalo, A., Mets, T., Martinmäki, K., Mauno, S., Kinnunen, U. & Rusko, H. 2011. Heart rate variability related to effort at work. Applied Ergonomics 42 (6), 830-838.

Van Amelsvoort, L., Schouten, E., Maan, A., Swenne, C. & Kok, F. 2000. Occupational determinants of heart rate variability. International Archives of Occupational and Environmental Health 73 (4), 255-262.

Vanderlei, L. C. M., Pastre, C. M., Hoshi, R. A., Carvalho, T. D. & Godoy, M. F. 2009. Basic notions of heart rate variability and its clinical applicability. Revista Brasileira de Cirurgia Cardiovascular 24 (2), 205-217.

Visser, M., Bouter, L. M., McQuillan, G. M., Wener, M. H., & Harris, T. B. 1999. Elevated C-reactive protein levels in overweight and obese adults. Jama 282 (22), 2131-2135.

Vrijkotte, T. G., van Doornen, L. J. & de Geus, E. J. 2000. Effects of work stress on ambulatory blood pressure, heart rate, and heart rate variability. Hypertension 35 (4), 880-886.

Waller, K., Kaprio, J. & Kujala, U. 2007. Associations between long-term physical activity, waist circumference and weight gain: a 30-year longitudinal twin study. International Journal of Obesity 32 (2), 353-361.

Waller, K., Kaprio, J., Lehtovirta, M., Silventoinen, K., Koskenvuo, M. & Kujala, U. 2010. Leisure-time physical activity and type 2 diabetes during a 28 year follow-up in twins. Diabetologia 53 (12), 2531-2537.

Warburton, D. E., Nicol, C. W. & Bredin, S. S. 2006. Health benefits of physical activity: the evidence. Canadian Medical Association journal 174 (6), 801-809.

Warren, J. M., Ekelund, U., Besson, H., Mezzani, A., Geladas, N., Vanhees, L. & Experts Panel 2010. Assessment of physical activity - a review of methodologies with reference to epidemiological research: a report of the exercise physiology section of the European Association of Cardiovascular Prevention and Rehabilitation. European Journal of Cardiovascular Prevention and Rehalibitation 17 (2), 127-139.

Weinsier, R. L., Hunter, G. R., Desmond, R. A., Byrne, N. M., Zuckerman, P. A. & Darnell, B. E. 2002. Free-living activity energy expenditure in women successful and unsuccessful at maintaining a normal body weight. The American Journal of Clinical Nutrition 75 (3), 499-504.

Westerterp, K. R. 2009. Assessment of physical activity: a critical appraisal. European Journal of Applied Physiology 105 (6), 823-828.

World Health Organization 2014. Global status report on non-communicable diseases 2014. [Access date April 18th, 2016] Available online at: http://apps.who.int/iris/bitstream/10665/148114/1/9789241564854_eng.pdf?ua=1.

World Health Organization 2010. Global recommendations on physical activity for health. [Access date February 5th, 2016] Available online at: http://apps.who.int/iris/bitstream/10665/44399/1/9789241599979_eng.pdf

Xiong, F. & Zhang, L. 2013. Role of the hypothalamic–pituitary–adrenal axis in developmental programming of health and disease. Frontiers in Neuroendocrinology 34 (1), 27-46.

Zahorska-Markiewicz, B., Kuagowska, E., Kucio, C. & Klin, M. 1993. Heart rate variability in obesity. International journal of obesity and related metabolic disorders: journal of the International Association for the Study of Obesity 17 (1), 21-23.

Zhai, L., Zhang, Y. & Zhang, D. 2015. Sedentary behaviour and the risk of depression: a meta-analysis. British Journal of Sports Medicine 49 (11), 705-709.

Zijlstra, F. R. & Sonnentag, S. 2006. After work is done: Psychological perspectives on recovery from work. European Journal of Work and Organizational Psychology 15 (2), 129-138.

Zulfiqar, U., Jurivich, D. A., Gao, W. & Singer, D. H. 2010. Relation of high heart rate variability to healthy longevity. The American Journal of Cardiology 105 (8), 1181-1185.

APPENDIX 1

The calculation of the level of physical activity was based on the following leisure-time physical activity questions. Questions are translated from Finnish.

How much of your daily journey to work is spent in walking, cycling, running?
[ ] not at all
[ ] less than 15 min
[ ] 15 min to less than half an hour
[ ] half an hour to less than one hour
[ ] one hour or more
[ ] I am presently not at work

How often you engage in physical activity during your leisure-time?
[ ] less than once a month
[ ] 1-2 times a month
[ ] 3-5 times a month
[ ] 6-10 times a month
[ ] 11-19 times a month
[ ] more than 20 times a month

Is your physical activity during leisure-time about as tiring on average as:
[ ] walking
[ ] alternatively walking and jogging
[ ] jogging (light run)
[ ] running

How long does one session of physical activity last on average?
[ ] less than 15 min
[ ] 15 min to less than half an hour
[ ] half an hour to less than one hour
[ ] one hour to less than two hours
[ ] two hours or more

APPENDIX 2

Exercise/ leisure-time physical activity-interview is translated from Finnish.

Please, choose from the list below which types of sports your leisure-time physical activity has included during the preceding 3 months?
Estimate the average level (1-4) of the intensity of each chosen sport according to the following description:

Level	Activity	Breathlessness	((Sweating))
1	outdoor recreation	no	((no))
2	light exercise	yes	((no))
3	moderate exercise	yes	((a little))
4	vigorous exercise	yes	((a lot))

	How many times per month?														
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Last week	One session last on average (h, min)	Level (1-4)
Commuting activity: walking															
Nordic walking															
Other walking															
Jogging/running															
Cross-country skiing															
Commuting activity: cycling															
Other cycling															
Swimming															
Golf															
Gymnastics, dancing															
Aerobic															
Gym															
Ball games															
Gardening etc.															
Hunting, berry picking etc.															
Fishing															
Repair work, building															
Rowing															
Forest work															
Other:															

APPENDIX 3

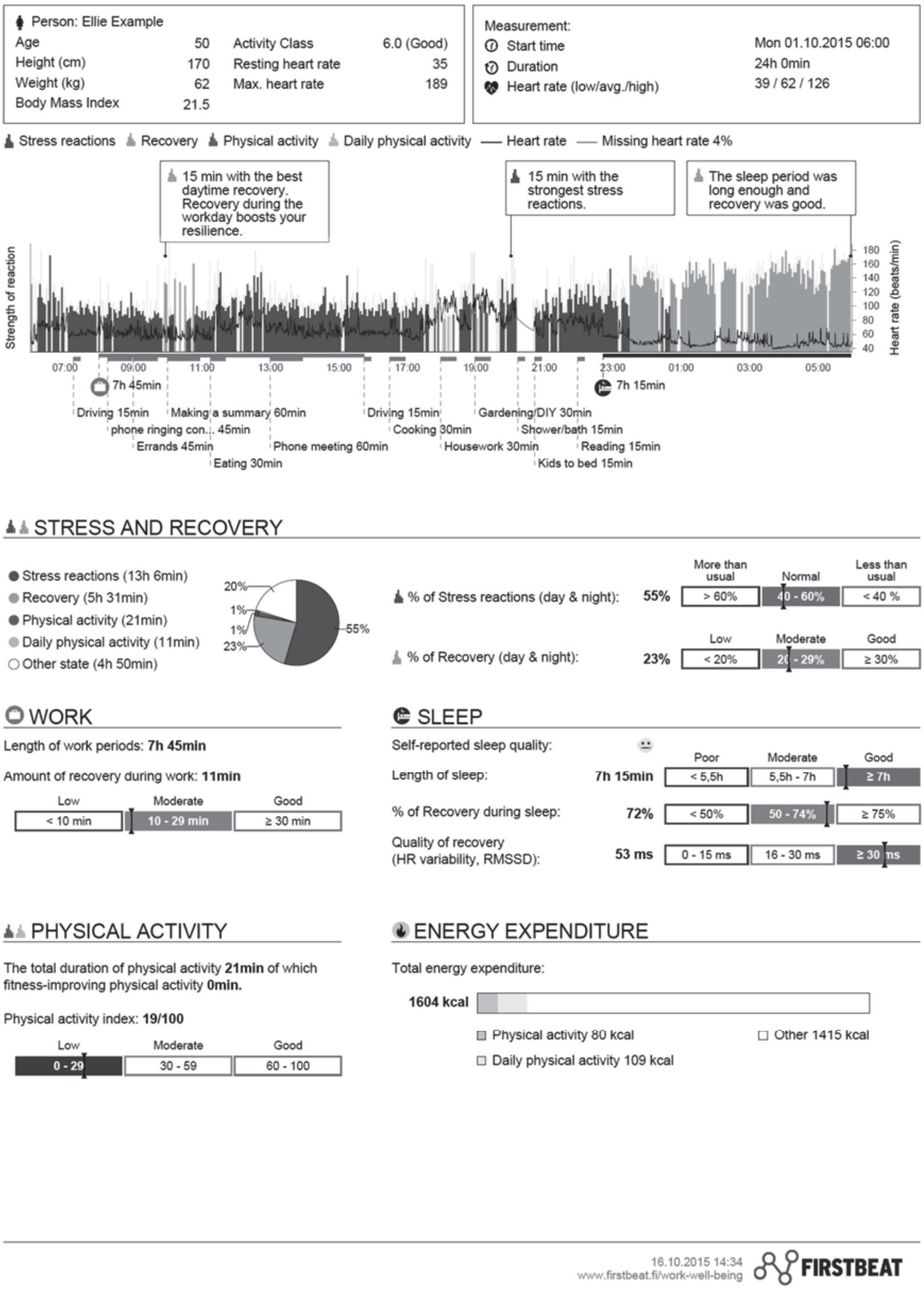
Perceived Stress Scale (PSS)

In the last month, how often...

	never	almost never	sometimes	fairly often	very often
1. have you been upset because of something that happened unexpectedly?	( )	( )	( )	( )	( )
2. have you felt that you were unable to control the important things in your life?	( )	( )	( )	( )	( )
3. have you felt nervous and "stressed"?	( )	( )	( )	( )	( )
4. have you dealt successfully with irritating life hassles?	( )	( )	( )	( )	( )
5. have you felt that you were effectively coping with important changes that were occurring in your life?	( )	( )	( )	( )	( )
6. have you felt confident about your ability to handle your personal problems?	( )	( )	( )	( )	( )
7. have you felt that things were going your way?	( )	( )	( )	( )	( )
8. have you found that you could not cope with all the things that you had to do?	( )	( )	( )	( )	( )
9. have you been able to control irritations in your life?	( )	( )	( )	( )	( )
10. have you felt that you were on top of things?	( )	( )	( )	( )	( )
11. have you been angered because of things that happened that were outside of your control?	( )	( )	( )	( )	( )
12. have you found yourself thinking about things that you have to accomplish?	( )	( )	( )	( )	( )
13. have you been able to control the way you spend your time?	( )	( )	( )	( )	( )
14. have you felt difficulties were piling up so high that you could not overcome them?	( )	( )	( )	( )	( )

APPENDIX 4

An example (1 of the 3 days) of the feedback from the wellbeing assessment of the participants.



ORIGINAL PUBLICATIONS

I

SUBJECTIVE STRESS, OBJECTIVE HEART RATE VARIABILITY-BASED STRESS, AND RECOVERY ON WORKDAYS AMONG OVERWEIGHT AND PSYCHOLOGICALLY DISTRESSED INDIVIDUALS: A CROSS-SECTIONAL STUDY

by

Föhr, T., Tolvanen, A., Myllymäki, T., Järvelä-Reijonen, E., Rantala, S., Korpela, R., Peuhkuri K., Kolehmainen, M., Puttonen, S., Lappalainen, R., Rusko, H. & Kujala, U. M. 2015.

Journal of Occupational Medicine and Toxicology 10:39, doi:10.1186/s12995-015-0081-6

Föhr *et al. Journal of Occupational Medicine and Toxicology* (2015) 10:39
DOI 10.1186/s12995-015-0081-6

JOURNAL OF OCCUPATIONAL MEDICINE AND TOXICOLOGY

RESEARCH Open Access

Subjective stress, objective heart rate variability-based stress, and recovery on workdays among overweight and psychologically distressed individuals: a cross-sectional study

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Abstract

Background: The present study aimed to investigate how subjective self-reported stress is associated with objective heart rate variability (HRV)-based stress and recovery on workdays. Another aim was to investigate how physical activity (PA), body composition, and age are associated with subjective stress, objective stress, and recovery.

Methods: Working-age participants ($n = 221$; 185 women, 36 men) in this cross-sectional study were overweight (body mass index, 25.3–40.1 kg/m^2) and psychologically distressed (≥3/12 points on the General Health Questionnaire). Objective stress and recovery were based on HRV recordings over 1–3 workdays. Subjective stress was assessed by the Perceived Stress Scale. PA level was determined by questionnaire, and body fat percentage was assessed by bioelectrical impedance analysis.

Results: Subjective stress was directly associated with objective stress ($P = 0.047$) and inversely with objective recovery ($P = 0.046$). These associations persisted after adjustments for sex, age, PA, and body fat percentage. Higher PA was associated with lower subjective stress ($P = 0.037$). Older age was associated with higher objective stress ($P < 0.001$). After further adjustment for alcohol consumption and regular medication, older age was associated with lower subjective stress ($P = 0.043$).

Conclusions: The present results suggest that subjective self-reported stress is associated with objective physiological stress, but they are also apparently affected by different factors. However, some of the found associations among these overweight and psychologically distressed participants with low inter-individual variation in PA are rather weak and the clinical value of the present findings should be studied further among participants with greater heterogeneity of stress, PA and body composition. However, these findings suggest that objective stress assessment provides an additional aspect to stress evaluation. Furthermore, the results provide valuable information for developing stress assessment methods.

Keywords: Heart rate variability, Objective stress, Perceived stress scale, Physiological stress, Physical activity, Psychological stress, Recovery, Stress assessment, Subjective stress, Work-related stress

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Background

Stress at work can be considered a major public health risk. In many theories and definitions, stress is determined as a psychological or physiological response of the organism to an external load [1]. Stress is associated with psychological disturbances, as well as physiological changes, such as lowered heart rate variability (HRV) [2]. It may even lead to cardiovascular diseases if prolonged [3, 4]. Recovery from stress is an important issue, as incomplete recovery is also suggested to be a risk factor for cardiovascular diseases [5]. Common to the definitions of recovery is that recovery occurs when the exposure to stress is over. Recovery repairs the negative effects of stress and it is a process during which individual recovers to the specific baseline level and is recovered from the possible previous loads [1]. Furthermore, stress has detrimental economic consequences due to decreased job satisfaction and increased sickness-related absences from work [6].

Most stress assessment methods primarily focus on an individual's subjective perception of stress. However, HRV has been proposed to be a good indicator for investigating the physiological effects of stress and recovery [2, 7]. HRV is the beat-to-beat (R–R interval) variation in times between the consecutive heartbeats expressed in normal sinus rhythm on an electrocardiogram (ECG) recording [8, 9]. HRV is very individual and it is modulated by both parasympathetic and sympathetic activity of the autonomic nervous system (ANS). Stress is associated with increased activation level of the body when sympathetic activity dominates the ANS whereas recovery is associated with reduced activation level of the body when parasympathetic activation dominates the ANS over sympathetic activity [10–12]. Studies investigating the association between self-reported, psychological stress and HRV in real-life settings have found controversial results (e.g. [7, 13–16]). Most of these studies have used traditional time- or frequency-domain measures of HRV. However, it is also possible to describe the state of stress and recovery using HRV-derived variables that include information that is difficult to obtain from traditional measures of HRV [7]. These novel variables take into account factors such as HRV-derived respiratory variables and individual resting heart rate (HR) and HRV values. Due to very high inter- and intra-individuality of HRV, new approaches which take into account individuality in HRV could provide additional insight into quantification of stress and recovery.

Physical activity (PA) can help the individual to build resources to buffer the negative effects of stress and promote his/her recovery from stress [17]. On the other hand, stress is suggested to be associated with physical inactivity (e.g. [7, 18, 19]) and being overweight [7, 20]. High stress levels could attenuate an individual's willingness or ability to engage in regular exercise and to be physically active [21], resulting in failure to achieve the beneficial effects of PA against stress.

The present study aimed to examine the associations between subjective self-reported psychological stress and objective physiological HRV-based measures of stress and recovery on workdays. The second aim was to investigate how PA, body composition, and age are associated with subjective stress, objective stress, and recovery.

Methods

Participants

The present cross-sectional study included individuals of different occupations with symptoms of metabolic syndrome and psychological distress, who met the inclusion criteria in an initial screening and underwent baseline measurements for a controlled and randomized trial called the Elixir study [22]. The initial purpose of the Elixir study was to investigate the effect of different psychological interventions on psychological and metabolic health. Data collection was carried out in three Finnish study centers at the universities of Helsinki, Jyväskylä, and Kuopio. The inclusion criteria were self-reported body mass index (BMI) of between 27–34.9 kg/m^2, and perceived psychological stress indicated by at least 3/12 points on the General Health Questionnaire [23]. The participants did not have any severe chronic illnesses, and any regularly taken medications were reported. Details of the inclusion and exclusion criteria have been reported previously [22].

Further inclusion criteria specifically for the present secondary cross-sectional baseline analyses were available data regarding objective stress and recovery (HRV recording) and subjective stress (Perceived Stress Scale; PSS). Individuals who used α- or β-adrenergic blocking agents affecting the heart were excluded from the present analysis. However, other regular medication was allowed. The final study group of the present analyses comprised of 221 individuals who also met the additional inclusion and exclusion criteria. Table 1 presents the characteristics of the participants. All participants were informed about the initial study, and they signed written informed consent prior to any measurements. This study was conducted according to the Declaration of Helsinki, and the study protocol was approved by the ethics committee of the Central Finland Health Care District.

Measurements

Objective stress and recovery were determined from recordings of the beat-to-beat R–R interval in real-life settings over 1–3 workdays. R–R interval data were collected using a Firstbeat Bodyguard measurement device (Firstbeat Technologies Ltd, Jyväskylä, Finland). The data were then analyzed using the Firstbeat Analysis Server

Table 1 Characteristics of the participants

	All (N = 221)		Female (N = 185)		Male (N = 36)	
	Mean	Range	Mean	Range	Mean	Range
Age (yrs)	48	26–60	48	26–60	45	31–60
Weight (kg)	87.7	64.0–120.1	85.4	64.0–113.9	99.3	83.8–120.1
Height (cm)	167.8	149.0–195.6	165.4	149.0–184.8	179.7	167.5–195.6
BMI (kg/[m]^2)	31.1	25.3–40.1	31.2	25.3–40.1	30.8	26.3–37.0
Body fat%	38.6	12.8–50.8	40.7	28.4–50.8	28.0	12.8–35.1
Physical activity (MET index[a])	3.2	0.0–18.0	3.0	0.0–15.3	4.3	0.1–18.0
Subjective stress (PSS[b])	26.5	7.0–52.0	26.5	7.0–52.0	26.2	17.0–38.0
Objective stress (stress index)	163.0	88.5–455.8	163.2	88.5–455.8	162.2	89.1–308.3
Objective recovery (stress balance)	0.35	−1.00–1.00	0.34	−1.00–1.00	0.40	−0.98–1.00

[a]MET-h/day, based on retrospective physical activity questionnaire
[b]Perceived Stress Scale

software (version 5.3.0.4), which included a powerful artifact correction feature for irregular ectopic beats, and signal noise. The original R-R interval series were resampled at the rate of 5 Hz by using linear interpolation to obtain equidistantly sampled time series, and second-by-second HRV indices were calculated with the short-time Fourier transform method by using constant duration Hanning window [24, 25]. Thereafter, the software categorizes the data into different physiological states such as stress, recovery, and physical activity of different intensities by taking into account individual characteristics (e.g. the individual levels and scales of HR and HRV, and the individual relationships between HRV and autonomic control e.g. [24]). Stress means sympathetic dominance of the ANS without metabolic requirements caused by physical activity whereas recovery means parasympathetic dominance of the ANS. In this categorization, second-by-second HRV indices, HRV-derived respiration rate, oxygen consumption calculated by HR, HRV-derived respiration rate, and on-off kinetics, and parameter describing excess-post exercise oxygen consumption are used with neural network data modeling [25–27] (for more details, see the white papers by Firstbeat Technologies Ltd [28]). The intensity of stress reaction is calculated from the HR, high frequency (0.15–0.4 Hz), and low frequency (0.04–0.15 Hz) components of HRV and respiratory variables. The intensity of stress is high when HR is elevated, HRV is reduced, and the frequency distribution of HRV is inconsistent because of changes in respiratory period. The intensity of recovery is calculated from the HR and high frequency component of HRV, and it is high when HR is low and high frequency component of HRV is high and regular. From the Firstbeat Analysis Server, the stress index was used as an indicator of objective stress and the stress balance value as an indicator of objective recovery. The stress index characterizes the magnitude of stress processes during the whole day. This index describes the mean intensity of the recognized stress reactions (theoretically ranging from 0 to ∞, ranging in our material 88.5 – 455.8). The stress balance value (ranging from −1 to 1) indicates the proportion of time of stress and recovery reactions during self-reported sleep periods during the measurement period. Values from 0.5 to 1 indicate good recovery, values from 0 to 0.5 indicate moderate recovery, and values from 0 to −1 indicate weak recovery [7].

The HRV data consisted of successfully recorded workdays, with an allowed maximum of 15 % regarding the grade of detected and corrected artifacts in R–R intervals. The values of the HRV-based variables of stress and recovery were the mean values of the workdays. Data from two workdays were included for 191 participants, from one workday for 20 participants, and from three workdays for 10 participants. For each monitored day, the participants reported their working hours, sleeping hours, and alcohol consumption in measurement diaries. Alcohol consumption was reported in standard units of approximately 12 g of ethanol (one unit: 33 centiliter [cl] beer, 12 cl red or white wine, 8 cl fortified wine, or 4 cl liquor).

Subjective stress during the preceding month was assessed using the 14-item PSS, which measures the degree to which situations in one's life are stressful on a 5-point scale ranging from 0 (never) to 4 (very often) [29]. PSS total scores are generally calculated by reversing the scores of the seven positive items and then summarizing the scores of all 14 items. Internal reliability (Cronbach's α) for the PSS was 0.86. To reduce the measurement error of the PSS sum score, we used a factor that included all 14 questions in the present analysis instead of the sum score.

PA was assessed using a questionnaire with items regarding present activity and changes within the last two months. The questionnaire included structured questions covering leisure-time PA and commuting activity [30, 31]. A multiple of the resting metabolic rate (MET) was assigned for each activity to describe the intensity of the form of PA. The MET indices for each form of PA were calculated by multiplying the intensity (MET), duration (h), and frequency of the activity, and the MET index was expressed as the sum score of different activities (MET-h/d).

Body composition was evaluated using bioelectrical impedance analysis (InBody720; Jyväskylä, Kuopio/Tanita BC-418 MA; Helsinki) in the morning after 10–12 h of fasting. This device provides information about the whole body fat percentage. Body weight and height were also measured during the same laboratory visit.

Statistical analysis

Statistical analyses were performed using Mplus version 5.21 [32]. Within this program, we used the MLR estimator, which comprises maximum likelihood with robust standard errors and with scale-corrected chi-square test values correcting for the effect of non-normality. To analyze the measurement structure of the PSS score, we used confirmatory factor analysis (CFA). Based on the results of the CFA the latent factor model was used in the estimation of the correlations and in structural equation modeling analysis to investigate the associations of objective stress and recovery with subjective stress, as well as to investigate the associations of PA, body composition, and age with objective and subjective stress. The significance level of the study was set at 0.05. The model fit was evaluated using the χ^2 test, comparative fit index (CFI), Tucker Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). For a good-fitting model, the χ^2 test is non-significant, CFI and TLI are at least 0.95, RMSEA is no more than 0.06, and SRMR no more than 0.08 [33].

Results

The one-factor solution for the PSS did not sufficiently fit the data (χ^2 (77) = 345.12, $P < 0.001$; CFI = 0.786; TLI = 0.747; RMSEA = 0.126; SRMR = 0.084); therefore, the factor structure was altered based on modification indices. The factor subjective stress was merged to contain two specific factors, as covariance existed between the residuals of questions 2, 3, 8, 12, 13, and 14 (related to perception of uncontrollable life) and the questions 1, 3, 6, and 11 (related to perception of overload) (Fig. 1). This estimated model fit the data well (χ^2 (66) = 109.25, $P < 0.001$; CFI = 0.966; TLI = 0.952; RMSEA = 0.054; SRMR = 0.044). All of the modification indices were lower than 4, indicating that there were no additional parameters that would have increased the fit of the model for the analysis.

Table 2 presents the results of the associations of subjective stress with objective stress and recovery. Subjective stress correlated with objective stress ($r = 0.139$, 95 % CI 0.002 to 0.276, $P = 0.047$) and with objective recovery ($r = -0.140$, 95 % CI −0.277 to −0.003, $P = 0.046$) without any adjustments (Model 1). In Model 2, the associations of subjective stress with objective stress and recovery were adjusted for sex and age. Subjective stress was associated with objective stress (residual $r = 0.209$, 95 % CI 0.075 to 0.343, $P = 0.002$) and with objective recovery (residual $r = -0.137$, 95 % CI −0.275 to 0.000, $P = 0.050$). Age was positively associated with objective stress (β = 0.435, 95 % CI 0.327 to 0.543, $P < 0.001$). Sex was not associated with subjective stress, objective stress, or recovery. The associations of subjective stress with objective stress and recovery were not influenced by further adjustment for alcohol consumption or for regular medication.

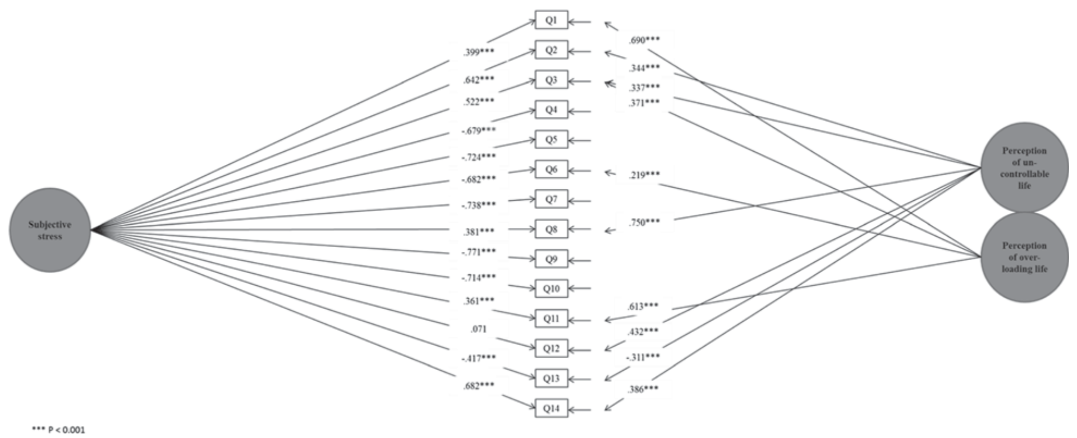

Fig. 1 The structure of the factor constructed of the questions of the Perceived Stress Scale (PSS). Factor loadings (standardized estimates) for the 14 questions, and loadings of the two specific factors for residual variances

Table 2 Correlations of subjective stress with objective stress and recovery

	Subjective stress							
	Model 1				Model 2			
	r	S.E.	95 % CI	*P*	r_e	S.E.	95 % CI	*P*
Objective stress (Stress index)	0.139	0.070	0.002 to 0.276	0.047	0.209	0.068	0.075 to 0.343	0.002
Objective recovery (Stress balance)	−0.140	0.070	−0.277 to −0.003	0.046	−0.137	0.070	−0.275 to 0.000	0.050

Standardized model results: correlation (r), residual correlation (r_e), standard error (S.E.), 95 % confidence interval (95 % CI), and *P* value
Model 1: no adjustments Model 2: age- and sex adjusted

Figure 2 presents the association of subjective stress with objective stress and recovery after adjustment for sex, age, PA, and body fat percentage. Subjective stress was associated with objective stress (residual $r = 0.217$, 95 % CI 0.084 to 0.351, $P = 0.001$) and recovery (residual $r = -0.146$, 95 % CI −0.283 to −0.009, $P = 0.037$). PA was negatively associated with subjective stress (β = −0.149, 95 % CI −0.289 to −0.009, $P = 0.037$). The negative association of subjective stress with body fat percentage was non-significant (β = −0.187, 95 % CI −0.384 to 0.011, $P = 0.064$). Objective stress and recovery were not associated with PA or body fat percentage. Sex was not associated with subjective stress, objective stress, or recovery. Age was positively associated with objective stress (β = 0.439, 95 % CI 0.330 to 0.547, $P < 0.001$). The results were not influenced by further adjustment for alcohol consumption or regular medication, except that age was negatively associated with subjective stress (β = −0.143, 95 % CI −0.282 to −0.004, $P = 0.043$).

Discussion

The present findings suggest that the higher the subjective self-reported stress the higher the objective HRV-based stress and the lower the objective HRV-based recovery on workdays. We also found that within our psychologically distressed and overweight study group, higher level of PA was associated with lower subjective stress.

Our results showed that higher subjective stress was associated with higher objective stress when adjusted for the effects of age and sex. This rather weak but statistically significant association strengthened after accounting for PA and body fat percentage. This finding is in line with those of previous studies. Uusitalo et al. [34] found that daily emotions at work and chronic work-related stress were associated with cardiac autonomic function. They used the same HRV-based measurement method as we did, and reported that the associations of HRV-based measures and the traditional HRV measures with subjective stress were alike. Other previous studies have reported similar findings using traditional time or frequency domain measures of HRV (e.g. [14, 16]). Collins et al. [14] observed that job strain and low decision latitude were associated with reduced cardiac vagal control, and that job strain was associated with elevated sympathetic control during working hours. These results of Collins et al. [14] were obtained from 24-h ECG recordings. Additionally, other study results obtained from both short-time [35, 36] and 24-h ECG

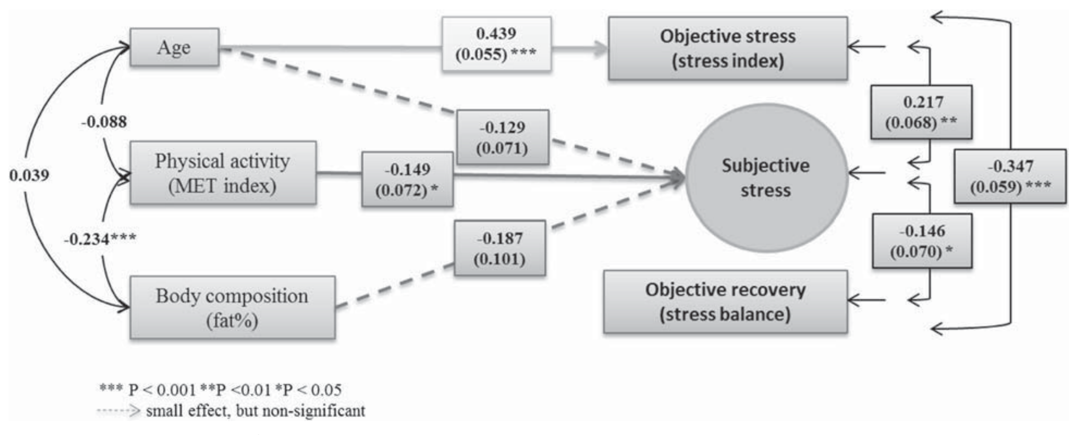

Fig. 2 Sex-adjusted associations of age, physical activity, and body composition with subjective stress, with objective stress, and with recovery. The presented values are standardized model results (estimate and standard error). Residual correlation and standard error between subjective stress and objective stress and recovery, and correlations between age, physical activity, and body composition are also presented

recordings (e.g. [37]) have observed the association between subjective stress and HRV with larger populations.

We also found that higher subjective stress was associated with lower objective recovery during sleep. This rather weak but statistically significant association strengthened after taken into account sex, age, PA and body fat percentage. This finding supports the previous study, which found that daily emotions at work were associated with night time traditional HRV measures [34]. In contrast, Hynynen et al. [13] found that low- and high-stress groups exhibited no differences in nocturnal traditional measures of HRV. Further studies are needed to investigate the association between subjective stress and HRV-based recovery during sleep. Recovery is an important factor in preventing the detrimental effects of stress, as good recovery during sleep has been suggested to confer protection from cardiovascular disease risk factors [2, 38]. An effort-recovery model shows that in cases of incomplete recovery, an employee must expend extra effort to perform properly at work [1].

The present results showed that higher level of PA was weakly but statistically significantly associated with lower levels of subjective stress among our overweight participants with low inter-individual variability in PA. Within our study group, PA was not associated with objective stress or objective recovery. The present study design does not enable us to draw any broader conclusions about the association between PA and subjective stress, and it remains unclear whether stress or inactivity is a cause or a consequence in this relationship. However, our finding of a negative association between PA and subjective stress supports the conclusions of previous studies. Hamer [39] suggests that regular exercise may have stress-buffering benefits largely because exercisers are more often in the post-exercise window when they encounter daily stressors. In line with our present cross-sectional finding, Kouvonen et al. [18] found that increased work-related stress was weakly associated with decreased PA during 6–8 year follow-up. In contrast to our present results, we found in our previous study [7] that a higher level of PA was associated with lower objective stress and higher objective recovery among participants with great inter-individual variability in their PA levels.

Within our study group, body fat percentage was not associated with objective stress or recovery. According to magnitude-based inference with confidence intervals [40, 41] our results showed a small negative effect of body fat percentage on subjective stress. In line with this, previous findings in large study groups suggest that a higher obesity level may confer protection from burnout (e.g. [42]). Whereas, our previous study found that a more favorable body composition was associated with lower objective stress and higher objective recovery [7] and obesity is known to cause stress to the body, as visceral obesity is a key factor in metabolic syndrome [43].

Here we also found that older age was associated with higher objective stress, but not with objective recovery. Additionally, the results showed an unclear negative non-significant association between age and subjective stress. Our inference is that any effect of age on subjective stress is at most small. HRV is individual, and is known to decrease with age [11]. The objective method presently used recognizes stress and recovery reactions and determines different physiological states of the body based on individual scaling of HR and HRV data. The presently used stress index as an indicator of magnitude of the objective stress reactions is, however, calculated from HR, HRV and respiratory variables during the recognized stress states on the whole day. Therefore, the aging-related decrease in HRV likely explains this finding to some extent and inhibits us to conclude that older employees were more sensitive to physiological stress. Whereas, the presently used stress balance value as an indicator of objective recovery was calculated from the recognized stress and recovery states during sleep, and this value takes into account all individuality in HRV. In the present study, age did not affect objective recovery during sleep. However, older persons seemed to perceive less stress than their younger counterparts. Further research on the association between age and objective stress, including the effect of PA, would be interesting and warranted.

In the present study, subjective stress was assessed by PSS. This scale has been found to be a reliable and valid measure of perceived stress. To analyze the measurement structure of the PSS score, we further used CFA to test whether the 14 questions of the PSS were consistent with the factor consisting of these 14 questions. We found that the fit factor solution included two specific factors. Based on the results of the CFA and to get more reliable results we used this factor solution as a variable of subjective stress in the present analysis. PSS assesses subjective stress during the preceding month. So, it is important to take into account that the present results provide information about the association of perceived stress over one month with the objective stress and recovery at the end of this month.

Subjective methods were used to assess both the level of stress and the level of PA. Even though, it is known that subjective assessment may include some reporting bias, it is a commonly used method for measuring stress. The most frequently utilized instrument is a questionnaire that has been widely criticized because it relies on individual self-reporting. In contrast, physiological measures represent objective data, which are considered to be more reliable as they are not affected by an individual's cognition, social context, or emotions [44]. Therefore, it is reasonable and important to develop objective measures of stress that acknowledge the physiological burden of stress. The assessment of PA was based on a questionnaire. However, this questionnaire took into account a long-term level of PA and may give more trustful information about individual's PA than an objective measurement from a short period.

HRV assessment is a promising clinical tool for assessing health and identifying health impairments [10, 24, 45]. However, due to a limited applicability of the traditional measures of HRV into changing and uncontrollable real-life setting, it is important to develop methods that apply HRV data and are able to provide valuable information on stress and recovery in individuals' everyday life. By utilizing both HRV and additional HRV-derived information it is possible to produce knowledge of physiological states, such as stress and recovery that is not available from the basic HRV measures which represent the average level of the autonomic activity over a period of the time. This kind of information can also be utilized in supporting lifestyle change. Previous findings also support the validity and reliability of the HRV-based method used in the present study [7, 34]. In addition to subjective assessment of stress, the method has been validated against neuroendocrine responses to stress. The indicators of stress and recovery during sleep have been found to be associated with free salivary cortisol after awakening [46]. As HRV measurement is dependent on the duration of the R – R interval recording [47], it is a strength of the present study that HR and HRV data were recorded in real-life settings over a rather long time period, usually two workdays. Secondly, the method produced stress- and recovery-related variables based on the HR, HRV, and respiratory variables. These variables are more informative for both health-care professionals and patients/clients than traditional measures of HRV and they are suitable for application in general health care.

Although, HRV assessment is a promising clinical tool for assessing health and identifying health impairments, several points must be considered regarding the HR- and HRV-based measurement of stress. HR and HRV are very individual, and are dependent on age and sex [10, 11, 24]. HRV decreases with age, and the variation is greater among female population. Therefore, it is important to account for age and gender, as well as PA, when investigating the associations of objective stress and recovery with subjective stress. The present study excluded subjects who used α- or β-blockers, as these drugs have substantial effects on HR and HRV. However, our participants included individuals using regular medication such as other cardiac medications or psychopharmacological, metabolic or analgesic medication. This could also potentially affect HR and HRV since many medications directly or indirectly act on the ANS [11]. Therefore, we also accounted for regular medication and alcohol consumption in our present analysis. These adjustments did not affect the associations of objective stress and recovery with subjective stress. However, it is important to acknowledge that the measurement was accomplished in real-life settings and it takes participant's word for confounding factors, such as medication and alcohol consumption.

The present study participants were psychologically distressed and overweight composing an ideal study group for investigating the association of subjective stress with objective stress and recovery. Furthermore, they represent a group of Finnish workers of different occupations, mainly trade and office workers. However, there were limited variations in the levels of psychological stress, fat percentage and PA within our participants. Therefore, these presently found associations should be studied further among more heterogeneous study group and the present results can thus be generalized to overweight individuals with psychological distress. It would have been interesting to further study the possible gender differences; however, such analyses were not reasonable within the present group due to the low number of men. Data collection was carried out in three study centers. However, adjustment for study center did not affect the results.

There is a recognized need for further research about the reliability of HRV measurement. The results of Cipryan & Litschmannova [48] suggest that researchers should be very cautious when drawing conclusions based only on short-term HRV analysis. Such methods as presently described and evaluated HRV-based method for assessing objective stress and recovery in real-life settings mainly over two workdays, are necessary to improve the reliability of HRV analysis and to provide informative and suitable variables for application in general health care and lifestyle counselling. This kind of individual counselling would be the optimal way to utilize HRV-based method in stress assessment. Real-life setting includes several uncontrollable confounding factors complicating the group-level analyzing of the data. This fact together with the participants' low inter-individual variation in the main variables of the present study result to the fact that the found associations are rather weak. From the perspective of magnitude-based inference with confidence intervals [40] there is a possibility that some of our findings are somewhat trivial. On the whole, there is a limited number of studies that have utilized long-term HRV monitoring and it is difficult to compare the present findings with the previous findings obtained from short-term ECG recordings and with studies that have used different measures than we did. Nevertheless, based on previous evidence, we assume that similar findings to our present findings and overall conclusion would have been reached by using traditional measures of HRV. More research with larger study populations and further follow-up studies are needed.

Conclusions

The present results suggest that subjective self-reported stress is associated with objective HRV-based stress and recovery. Subjective psychological and objective physiological stress are apparently affected by different factors, such as PA. However, some of the found associations among the overweight and psychologically distressed participants with low inter-individual variation in PA are rather weak and the clinical value of the present findings should be studied further among participants with greater heterogeneity of stress, PA and body composition. However, these findings suggest that the presently described method for objective stress assessment provides an additional and important aspect to stress assessment. Furthermore, the results provide valuable information for the development of stress assessment methods.

Abbreviations

ANS: Autonomic nervous system; BMI: Body mass index; CFA: Confirmatory factor analyses; CFI: Comparative fit index; ECG: Electrocardiogram; HR: Heart rate; HRV: Heart rate variability; MET: Multiple of the resting metabolic rate; PA: Physical activity; PSS: Perceived stress scale; RMSEA: Root mean square error of approximation; SRMR: Standardized root mean square residual; TLI: Tucker Lewis index.

Competing interests

T. Myllymäki is an employee of and H. Rusko is a stockowner in Firstbeat Technologies Ltd. They did not contribute to writing the conclusions of the study. The authors declare that they have no competing interests.

Authors' contributions

Study conception and design: TF, AT, RK, MK, RL, UK. Data acquisition: TF, TM, EJ-R, SR, KP, UK. Data analysis and interpretation: TF, AT, TM, EJ-R, SR, RK, KP, MK, SP, RL, HR, UK. Statistical analysis: TF, AT. Drafting the manuscript: TF. Critical revision of the manuscript for important intellectual content: TF, AT, TM, EJ-R, SR, RK, KP, MK, SP, RL, HR, UK. Final approval of the version to be published: TF, AT, TM, EJ-R, SR, RK, KP, MK, SP, RL, HR, UK. Obtained funding: TF, RK, MK, RL, UK. Administrative, technical, or material support: AT, RK, MK, SP, RL, UK.

Acknowledgements

This study was supported by the SalWe Research Program for Mind and Body (Tekes - the Finnish Funding Agency for Technology and Innovation grant 1104/10). T. Föhr's work was supported by a personal grant from the Juho Vainio Foundation.

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Received: 23 September 2014 Accepted: 19 October 2015
Published online: 26 October 2015

References

1. Meijman TF, Mulder G. Psychological aspects of workload. In: Handbook of work and organizational psychology: Work psychology. 2nd ed. United Kingdom: Redwood Books Ltd; 1998. p. 5–33.
2. Van Amelsvoort LGPM, Schouten EG, Maan AC, Swenne CA, Kok FJ. Occupational determinants of heart rate variability. Intern Arch Occup Environ Health. 2000;73 Suppl 4:255–62.
3. Chandola T, Heraclides A, Kumari M. Psychophysiological biomarkers of workplace stressors. Neurosci Biobehav Rev. 2010;35 Suppl 1:51–7.
4. Kivimäki M, Nyberg ST, Batty GD, Fransson EI, Heikkilä K, Alfredsson L, et al. Job strain as a risk factor for coronary heart disease: a collaborative meta-analysis of individual participant data. Lancet. 2012;380 Suppl 9852:1491–7.
5. Kivimäki M, Leino-Arjas P, Kaila-Kangas L, Luukkonen R, Vahtera J, Elovainio M, et al. Is incomplete recovery from work a risk marker of cardiovascular death? Prospective evidence from industrial employees. Psychosom Med. 2006;68 Suppl 3:402–7.
6. Duijts SF, Kant I, Swaen GM, van den Brandt PA, Zeegers M. A meta-analysis of observational studies identifies predictors of sickness absence. J Clin Epidemiol. 2007;60 Suppl 11:1105–15.
7. Teisala T, Mutikainen S, Tolvanen A, Rottensteiner M, Leskinen T, Kaprio J, et al. Associations of physical activity, fitness, and body composition with heart rate variability–based indicators of stress and recovery on workdays: a cross-sectional study. J Occup Med Toxicol. 2014;9:16.
8. Reed MJ, Robertson CE, Addison PS. Heart rate variability measurements and the prediction of ventricular arrhythmias. QJM. 2005;98 Suppl 2:87–95.
9. McMillan DE. Interpreting heart rate variability sleep/wake patterns in cardiac patients. J Cardiovasc Nurs. 2002;17 Suppl 1:69–81.
10. Acharya UR, Joseph KP, Kannathal N, Lim CM, Suri JS. Heart rate variability: a review. Med Bio Eng Comput. 2006;44:1031–51.
11. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Circulation. 1996;93 Suppl 5:1043–65.
12. Malliani A, Pagani M, Lombardi F, Gerutti S. Cardiovascular neural regulation explored in the frequency domain. Circulation. 1991;84 Suppl 2:482–92.
13. Hynynen E, Konttinen N, Kinnunen U, Kyröläinen H, Rusko H. The incidence of stress symptoms and heart rate variability during sleep and orthostatic test. Eur J Appl Physiol. 2011;111 Suppl 5:733–41.
14. Collins SM, Karasek RA, Costas K. Job strain and autonomic indices of cardiovascular disease risk. Am J Ind Med. 2005;48 Suppl 3:182–93.
15. Riese H, Van Doornen LJ, Houtman IL, De Geus EJ. Job strain in relation to ambulatory blood pressure, heart rate, and heart rate variability among female nurses. Scand J Work Environ Health. 2004;30 Suppl 6:477–85.
16. Hanson EKS, Godaert GLR, Maas CJM, Meijman TF. Vagal cardiac control throughout the day: the relative importance of effort–reward imbalance and within-day measurements of mood, demand and satisfaction. Biol Psychol. 2001;56 Suppl 1:23–44.
17. Gerber M, Pühse U. Do exercise and fitness protect against stress-induced health complaints? A review of the literature. Scand J Publ Health. 2009;37 Suppl 8:801–19.
18. Kouvonen A, Vahtera J, Oksanen T, Pentti J, Väänänen AK, Heponiemi T, et al. Chronic workplace stress and insufficient physical activity: a cohort study. Occup Environ Med. 2013;70 Suppl 1:3–8.
19. Ahola K, Pulkki-Råback L, Kouvonen A, Rossi H, Aromaa A, Lönnqvist J. Burnout and behavior-related health risk factors: results from the population-based finnish health 2000 study. J Occup Env Med. 2012;54 Suppl 1:17–22.
20. Iversen LB, Strandberg-Larsen K, Prescott E, Schnohr P, Rod NH. Psychosocial risk factors, weight changes and risk of obesity: the Copenhagen City heart study. Eur J Epidemiol. 2012;27 Suppl 2:119–30.
21. Sonnentag S, Jelden S. Job stressors and the pursuit of sport activities: a day-level perspective. J Occup Health Psychol. 2009;14 Suppl 2:165–81.
22. Lappalainen R, Sairanen E, Järvelä E, Rantala S, Korpela R, Puttonen S, et al. The effectiveness and applicability of different lifestyle interventions for enhancing wellbeing: the study design for a randomized controlled trial for persons with metabolic syndrome risk factors and psychological distress. BMC Publ Health. 2014;14 Suppl 1:310.
23. Makowska Z, Merecz D, Moscicka A, Kolasa W. The validity of general health questionnaires, GHQ-12 and GHQ-28, in mental health studies of working people. Int J Occup Med Environ Health. 2002;15 Suppl 4:353–62.

24. Martinmäki K, Rusko H, Kooistra L, Kettunen J, Saalasti S. Intraindividual validation of heart rate variability indexes to measure vagal effects on hearts. Am J Physiol Heart Circ Physiol. 2006;290:640–7.
25. Saalasti S. Neural networks for heart rate time series analysis. In: PhD Thesis. Finland, Jyväskylä Studies in Computing 33. Jyväskylä: Department of Mathematical Information Technology, University of Jyväskylä; 2003.
26. Kettunen J, Saalasti S, inventors; Firstbeat Technologies Ltd, assignee. Procedure for deriving reliable information on respiratory activity from heart period measurement. United States: patent US 20050209521A1; 2005.
27. Kettunen J, Saalasti S, inventors; Firstbeat Technologies Ltd, assignee. Procedure for detection of stress by segmentation and analyzing heart beat signal. United States: patent US 007330752B2; 2008.
28. White papers [http://www.firstbeat.com/physiology/white-papers]
29. Cohen S, Kamarck T, Mermelstein R. A global measure of perceived stress. J Health Soc Behav. 1983;24 Suppl 4:385–96.
30. Kujala UM, Kaprio J, Sarna S, Koskenvuo M. Relationship of leisure-time physical activity and mortality: The finnish twin cohort. JAMA. 1998;279 Suppl 6:440–4.
31. Waller K, Kaprio J, Kujala UM. Associations between long-term physical activity, waist circumference and weight gain: a 30-year longitudinal twin study. Int J Obes. 2007;32 Suppl 2:353–61.
32. Muthén LK, Muthén BO. Mplus user's guide. 7th ed. Muthén & Muthén: Los Angeles: CA; 1998.
33. Hu LT, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. Struct Equ Model. 1999;6 Suppl 1:1–55.
34. Uusitalo A, Mets T, Martinmäki K, Mauno S, Kinnunen U, Rusko H. Heart rate variability related to effort at work. Appl Ergon. 2011;42 Suppl 6:830–8.
35. Hintsanen M, Elovainio M, Puttonen S, Kivimäki M, Koskinen T, Raitakari OT, et al. Effort—reward imbalance, heart rate, and heart rate variability: the cardiovascular risk in young finns study. Int J Behav Med. 2007;14 Suppl 4:202–12.
36. Zanstra YJ, Schellekens JM, Schaap C, Kooistra L. Vagal and sympathetic activity in burnouts during a mentally demanding workday. Psychosom Med. 2006;68 Suppl 4:583–90.
37. Vrijkotte TG, van Doornen LJ, de Geus EJ. Effects of work stress on ambulatory blood pressure, heart rate, and heart rate variability. Hypertension. 2000;35 Suppl 4:880–6.
38. Steptoe A, Marmot M. Impaired cardiovascular recovery following stress predicts 3-year increases in blood pressure. J Hypertens. 2005;23 Suppl 3:529–36.
39. Hamer M. Psychosocial stress and cardiovascular disease risk: the role of physical activity. Psychosom Med. 2012;74 Suppl 9:896–903.
40. Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. Sportscience. 2005;9:6–13.
41. Cohen J. A power primer. Psychol Bull. 1992;112 Suppl 1:155–9.
42. Armon G, Shirom A, Berliner S, Shapira I, Melamed S. A prospective study of the association between obesity and burnout among apparently healthy men and women. J Occup Health Psychol. 2008;13 Suppl 1:43–57.
43. Rosmond R. Role of stress in the pathogenesis of the metabolic syndrome. Psychoneuroendocrinology. 2005;30 Suppl 1:1–10.
44. Kompier M. Assessing the psychosocial work environment-"subjective" versus"objective" measurement. Scand J Work Environ Health. 2005;31 Suppl 6:405–8.
45. Vanderlei LCM, Pastre CM, Hoshi RA, Carvalho TD, Godoy MF. Basic notions of heart rate variability and its clinical applicability. Rev Bras Cir Cardiovasc. 2009;24 Suppl 2:205–17.
46. Rusko H, Rönkä T, Uusitalo A, Kinnunen U, Mauno S, Feldt T, et al. Stress and relaxation during sleep and awake time, and their associations with free salivary cortisol after awakening. Nordic Ergonomics Society congress 2006 [http://www.firstbeat.com/userData/firstbeat/download/rusko_et_al_nes_2006_congress.pdf]
47. Pinna G, Maestri R, Torunski A, Danilowicz-Szymanowicz L, Szwoch M, La Rovere M, et al. Heart rate variability measures: a fresh look at reliability. Clin Sci. 2007;113:131–40.
48. Cipryan L, Litschmannova M. Intra-day and inter-day reliability of heart rate variability measurement. J Sports Sci. 2013;31 Suppl 2:150–8.

II

PHYSICAL ACTIVITY, HEART RATE VARIABILITY–BASED STRESS AND RECOVERY, AND SUBJECTIVE STRESS DURING A 9-MONTH STUDY PERIOD

by

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Scandinavian Journal of Medicine & Science in Sports, doi: 10.1111/sms.12683.

III

ASSOCIATIONS OF PHYSICAL ACTIVITY, FITNESS, AND BODY COMPOSITION WITH HEART RATE VARIABILITY–BASED INDICATORS OF STRESS AND RECOVERY ON WORKDAYS: A CROSS-SECTIONAL STUDY

by

Teisala, T., Mutikainen, S., Tolvanen, A., Rottensteiner, M., Leskinen, T., Kaprio, J., Kolehmainen, M., Rusko, H. & Kujala, U. M. 2014.

Journal of Occupational Medicine and Toxicology 9:16, doi:10.1186/1745-6673-9-16

Teisala *et al. Journal of Occupational Medicine and Toxicology* 2014, **9**:16
http://www.occup-med.com/content/9/1/16

JOURNAL OF OCCUPATIONAL MEDICINE AND TOXICOLOGY

RESEARCH **Open Access**

Associations of physical activity, fitness, and body composition with heart rate variability–based indicators of stress and recovery on workdays: a cross-sectional study

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Abstract

Background: The purpose of this study was to investigate how physical activity (PA), cardiorespiratory fitness (CRF), and body composition are associated with heart rate variability (HRV)-based indicators of stress and recovery on workdays. Additionally, we evaluated the association of objectively measured stress with self-reported burnout symptoms.

Methods: Participants of this cross-sectional study were 81 healthy males (age range 26–40 y). Stress and recovery on workdays were measured objectively based on HRV recordings. CRF and anthropometry were assessed in laboratory conditions. The level of PA was based on a detailed PA interview (MET index [MET-h/d]) and self-reported activity class.

Results: PA, CRF, and body composition were significantly associated with levels of stress and recovery on workdays. MET index ($P < 0.001$), activity class ($P = 0.001$), and CRF ($P = 0.019$) were negatively associated with stress during working hours whereas body fat percentage ($P = 0.005$) was positively associated. Overall, 27.5% of the variance of total stress on workdays ($P = 0.001$) was accounted for by PA, CRF, and body composition. Body fat percentage and body mass index were negatively associated with night-time recovery whereas CRF was positively associated. Objective work stress was associated ($P = 0.003$) with subjective burnout symptoms.

Conclusions: PA, CRF, and body composition are associated with HRV-based stress and recovery levels, which needs to be taken into account in the measurement, prevention, and treatment of work-related stress. The HRV-based method used to determine work-related stress and recovery was associated with self-reported burnout symptoms, but more research on the clinical importance of the methodology is needed.

Keywords: Body composition, Body fat percentage, BMI, Cardiorespiratory fitness, HRV, Physical activity, Recovery, Working hours, Work stress

Background

Physical activity (PA) is one of the factors that protects against stress [1]. Exercise and psychological stress have similar acute physiological effects because both result in potent increases in cardiovascular, sympathetic, and hypothalamic pituitary adrenocortical responses and decreases in parasympathetic responses [2]. Repeated bouts of exercise lead to physiological adaptations, including decreased resting heart rate (HR) and blood pressure and increased parasympathetic activity [3]. The theory of "cross-stressor adaptation" suggests that regular PA and good fitness lead to adaptations in response to both exercise and psychological stressors [2,4].

The assessment of heart rate variability (HRV) has gained importance as a technique to explore the function of the autonomic nervous system (ANS) and has been widely used to diagnose both psychological and physiological disorders [5]. HRV is the beat-to-beat variation in time of consecutive heartbeats expressed in normal sinus rhythm on an electrocardiogram [6,7]. The separate rhythmic

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contributions from sympathetic and parasympathetic autonomic activity modulate the heart's R wave to R wave intervals (RR intervals) of the QRS complex at distinct frequencies [8]. Both sympathetic and parasympathetic activity have been suggested to be associated with the low frequency (LF) range (0.04–0.15 Hz) because parasympathetic activity is a major contributor to the high frequency (HF) range (0.15–0.4 Hz) component in modulation of frequencies of the HR [9,10]. Higher HRV characterizes a healthy person with efficient autonomic mechanisms and good adaptation ability while lower HRV is an indicator of abnormal and insufficient adaptation of the ANS [7,11]. Reduced HRV is suggested to be associated with harmful events in health [12].

A greater amount of reported stress is suggested to be associated with lower HRV [13]. Also, the effects of PA, cardiorespiratory fitness (CRF), and adiposity on HRV profile have been of interest. Chronic exercise increases HRV [14-16], and favorable HRV profiles are associated with higher levels of PA [17] and better CRF [18]. Additionally, obesity has been associated with altered ANS activity [19]. Some studies have found HRV profiles to be relatively poor among obese subjects [20,21] and to improve with weight loss [22].

Work-related stress and physical inactivity are major concerns in society today. The current interest is in reducing both work-related stress and inactivity, and objective methods, such as the HRV-based approach, are needed to diagnose stress symptoms. To make recording of HRV a practical tool for field measurements, new approaches for HRV analysis are needed. For instance, age is an important determinant of HRV, which also has a large inter-individual variability [9,23]. Firstbeat Technologies Ltd. has been developing this kind of diagnostic tool to measure and define stress and recovery based on individual values for HR and HRV (for more information, see the company's web page [24]). Some stress and recovery variables, calculated with this tool, are suggested to be related to chronic work stress and emotions at work [25]. Using this tool, we investigated how different indicators of PA, CRF, and body composition, which are related to each other, are associated with HRV-based indicators of stress and recovery on workdays among healthy young men. The secondary aim was to evaluate the association between objectively measured stress and self-reported burnout symptoms.

Methods

Subjects

The population of this cross-sectional study consisted of groups from two separate studies, the FitFatTwin study (FFT study) and the Body & Future Health study (BFH study). The identical measurements of the cross-sectional FFT study and the baseline measurements of the BHF were pooled for this analysis. In total, 46 men (23 monozygotic twin pairs) participated in the FFT study. The BFH study included 37 men, two of whom were excluded from this study because their HRV recordings included only days off from work. Altogether, 81 healthy males (age range 26–40 y) who were not on regular medication were included in the present study. The twin study was enriched with pairs having within-pair differences in their PA habits. Because the BFH study was originally planned to investigate overweight and physically inactive individuals, it involved the following inclusion criteria: BMI 25.0–35.0 kg/m^2, waist circumference ≥94 cm, no vigorous exercise (>20 min/session) more than twice a week, and no smoking; for more information, see the registered controlled trial protocol [26]. Levels of HRV-based stress and recovery did not differ between the participants of these two studies. However, the participants from the FFT study had more favorable body composition, better CRF, and a higher self-rated activity class. The characteristics of the participants of the present study are presented in Table 1.

Both studies were conducted according to the ethical rules stated in the Declaration of Helsinki. All participants were informed about the study, and they signed written informed consent prior to any measurements. The study

Table 1 Characteristics of the study population

	Mean	Range
Age (y)	34	26–40
Weight (kg)	83.5	51.3–123.2
Height (cm)	179.1	156.5–198.0
BMI (kg/[m]^2)	26.0	19.8–35.0
Body fat%	24.5	7.6–41.8
VO_{2max}[a] (ml/kg/min)	39.6	23.3–72.6
MET index[b]	3.5	0.1–27.7
Activity class (0–10)	4.4	0.0–9.5
Working time (h)	8.4	2.8–16.0
Sleeping time (h)	7.7	4.7–10.3
Bergen burnout inventory total scores[c]	36	16–74
Firstbeat variables		
Work stress (%)	72.8	14.5–99.2
Total stress (%)	49.9	12.6–79.1
Stress index	122.3	80.5–193.3
RMSSD (sleep)	56.78	22.6–150.6
Stress balance (−1 to 1)	0.69	−0.43–1.00
Total recovery (%)	29.3	4.6–67.0
Recovery index (24 h)	92.2	74.0–112.2
Recovery index (sleep)	111.4	45.8–246.9

(n = 81).
[a]n = 78 [b]MET-h/day, based on retrospective PA interview [c]n = 80.

protocols were approved by the ethics committee of the Central Finland Health Care District.

Measurements

The stress and recovery variables were calculated objectively from the HR and HRV recordings, which were executed over three days using Bodyguard, a measurement device developed by Firstbeat Technologies Ltd. (Jyväskylä, Finland). The HRV recordings from these three days were downloaded with Firstbeat Health Software (version 3.1.1.0.). The Firstbeat Health Software first scans the recorded ambulatory RR interval data through an artifact detection filter to perform an initial correction of falsely detected, missed, and premature heart beats [27]. The data were transferred to the Matlab environment (R2007B), where the analyses of physiological variables describing stress and recovery were performed with the Firstbeat Analysis Server program (version 5.3.0.4). This program calculates HRV indices second-by-second using the short-time Fourier transform method and HR- and HRV-derived variables of respiration rate and oxygen consumption using neural network modeling of data [27-29] (for more details, see the white paper by Firstbeat Technologies Ltd. [30]). The program also calculates second-by-second indices of recovery and stress, reflecting activities of the sympathetic (absolute stress vector, ASV) and parasympathetic (absolute recovery vector, ARV) nervous systems. The ASV is calculated from the HR, HF, and LF components and respiratory variables. The ASV is high when HR is elevated, HRV is reduced, and the frequency distribution of HRV is inconsistent because of changes in respiratory period. The ARV, which is calculated from the HR and HF components, is high when HR is close to the basic resting level and HRV is high and regular. The program takes into account individual basic resting HR and HRV values in the determination of the physiological states of the body, including PA, stress state, recovery state, or unrecognized state, and detected based on the above-mentioned variables. The stress and recovery variables used in the present study are based on Firstbeat Analysis Server analyses and are described in Table 2. These variables included the traditional HRV variable RMSSD (root mean square of successive differences), which is a time domain measure of HRV, and plots HRV as the change in normal RR intervals over time [31].

The HRV data consisted of successfully recorded (RR intervals corrected max 25 percentages) workdays. The stress and recovery values were the mean values of the workdays with the number of days being one (n = 10), two (n = 70), or three (n = 1). The stress and recovery variables were determined from the whole recording day (24 h) or only from working hours or sleeping hours. Working hours, sleeping time, and alcohol consumption were determined from the participants' measurement diaries, which they were advised to keep over the measurement period. Alcohol consumption was reported daily in standard units of approximately 12 g of ethanol (one unit: 33 centiliter [cl] beer or 12 cl red or white wine or 8 cl fortified wine or 4 cl liquor).

The Bergen Burnout Inventory (BBI) was used in the assessment of occupational burnout. This inventory is employed in some Finnish occupational health services to monitor and screen stress levels [32] and includes 15 questions concerning three subcategories of burnout: exhaustive fatigue, cynicism, and impaired occupational self-respect. Answers to the 15 questions were given using a Likert-type response scale, which was scored from 1 (totally disagree) to 6 (totally agree), and the total scores were between 15 and 90 [33].

Body weight and height were measured in the morning. The body mass index (BMI) is computed as weight/height^2 (kg/m^2). The whole body fat percentage was evaluated after fasting 10–12 h using dual-energy X-ray absorptiometry (GE Lunar Prodigy Advance, GE Healthcare). The software used for picture handling and analysis was enCORE™ 2009, version 13.20 (GE Healthcare).

The volume of PA (MET index) was retrospectively inferred using a modified version [34] of the Kuopio Ischemic Heart Disease Risk Factor Study Questionnaire [35], which included questions on leisure-time PA and PA during journeys to and from work, as well as daily activities such as gardening and berry picking. Monthly frequency, mean duration, and mean intensity of each form of activity were evaluated. A multiple of the resting metabolic rate (MET) was assigned for each activity to describe the intensity of the form of PA. The 3-month (BFH study) and 12-month (FFT study) MET indexes for each form of PA were calculated by multiplying the intensity (MET), duration (h), and monthly frequency of the activity, and the MET index was expressed as the sum score of different activities (MET-h/d).

The other method used to estimate PA level was self-reported activity class using a 0–10 scale to represent the activity level of the previous 2–3 months. The values from 0 to 7 were modified from Ross and Jackson's [36] scale. The values from 7.5 to 10 were added by Firstbeat to include more seriously training individuals and athletes in the scale (for more details, see the white paper by Firstbeat Technologies Ltd. [37]).

CRF was assessed using the cycle ergometer test and a slightly modified World Health Organization protocol [38] with 2-min stages and 25 W/stage increases in workload. The test was submaximal in the BHF study and maximal with breath-by-breath respiratory gas-exchange analysis in the FFT study. The submaximal cycle ergometer test was ended after the workload during which the tested person achieved the submaximal HR level (85–88% from the maximal HR), which was defined from maximal

Table 2 The description of variables of stress and recovery based on firstbeat analysis server

Stress variables For non-exercise data segments, continuous indices of stress are used to identify the time when the body is in a stress state. Stress state is defined as an increased activation in the body when sympathetic nervous system activity is dominating and parasympathetic activation is decreased. Stress can be induced by external and internal stress factors, and the definition of the stress state does not take into account the nature of the stress response, i.e., whether it is positive or negative.	
Work stress	The percentage of stress time during working hours
Total stress	The percentage of stress time in a workday (including leisure time and night)
Stress index	Absolute value characterizing the magnitude of stress processes on a workday (including leisure time and night)
Recovery variables, 24 hours Continuous indices of recovery are used to identify the time when the body is in a recovery state. Recovery state is defined as a decreased activation in the body during recovery, rest, and/or peaceful working. This state is related to the lack of external and internal stress factors, and parasympathetic activation is dominating.	
Total recovery	The percentage of recovery time in a workday (including leisure time and night)
Recovery index	Absolute value characterizing the magnitude of recovery processes in a workday (including leisure time and night)
Recovery variables, sleep time	
RMSSD	Average of the RMSSD (root mean square of successive differences) vector values during sleep periods. High RMSSD values are associated with increased parasympathetic activity and good recovery while low values during rest indicate poor recovery. The RMSSD value should be over 20 during sleep in a normal situation.
Stress balance	Indicates proportion of time of stress and recovery reactions during sleep periods in the measurement period; the used values are from −1 to 1. Values from 0.5 to 1 indicate good recovery; values from 0 to 0.5 indicate moderate recovery; and values from 0 to −1 indicate weak recovery.
Recovery index	The recovery index gives an estimate of a person's recovery during sleep time. The 4-h window for determining the recovery index is set to start 30 min after going to bed. The index summarizes several factors, including RMSSD and other HRV variables, and takes into account the other functions of ANS while determining the value for the index.

HR based on the participant's age (210 − (0.65 × age)). In the FFT study, three people did not participate in the maximal cycle ergometer test, and in the case of seven participants, a submaximal test was performed instead of the maximal test for health or motivational reasons. In the analyses, the values used for the maximal oxygen consumption (VO_{2max}) are the results of submaximal workload-based calculations for all participants. VO_{2max} was calculated from the submaximal test values of the maximal cycle ergometer test (n = 36). The correlation between this calculation from submaximal workloads and the value from the maximal oxygen consumption test was significant ($P < 0.001$).

Statistical analysis

Statistical analyses were performed using Mplus version 7 [39]. The statistical significance was set at $P \leq 0.05$. The estimator used was maximum likelihood with robust standard errors that are robust against non-normality. The effect of clustered data (twins) was controlled using the type complex definition in Mplus. A few missing values (VO_{2max} n = 3 and BBI n = 1) were inferred to be missing at random. Because the variables under interest are known to be related to each other, structural equation modeling was used to investigate how PA, fitness, and body composition are associated with HRV-based indicators of stress and recovery. In the first stage, estimates of each independent variable (body fat percentage, BMI, VO_{2max}, MET index, and activity class) were determined to explain the dependent stress and recovery variables. In the second stage, to investigate how much of the variance of the stress and recovery variables is explained by PA, fitness, and body composition together, a latent factor variable was formed from the MET index, activity class, VO_{2max}, body fat percentage, and BMI. In addition, structural equation modeling was used to investigate the association of the HRV-based stress and recovery variables with the BBI total scores.

The model fit was evaluated using the χ^2 test, comparative fit index (CFI), Tucker Lewis Index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). For a good-fitting model, the χ^2 test is non-significant; CFI and TLI are at least 0.95; RMSEA is no more than 0.06; and SRMR no more than 0.08 [40].

Results

Body fat percentage was positively associated (β = 0.306, $P = 0.005$) whereas VO_{2max} (β = −0.311, $P = 0.019$), MET index (β = −0.304, $P < 0.001$), and activity class (β = −0.326, $P = 0.001$) were negatively associated with HRV-based work stress. Similarly to works stress, the other HRV-based stress variables were associated with body composition, CRF, and PA. However, BMI was positively associated with total stress (β = 0.272, $P = 0.003$) and stress index (β = 0.478, $P < 0.001$). MET index was not associated with stress index ($P = 0.440$).

The indicators of recovery during night-time sleep (RMSSD, stress balance, recovery index) were negatively associated with body fat percentage and BMI and positively associated with VO_{2max}. Activity class was positively associated with stress balance value (β = 0.237, $P = 0.025$).

Body fat percentage (β = −0.445, $P < 0.001$) and BMI (β = −0.355, $P < 0.001$) were negatively associated whereas VO_{2max} (β = 0.465, $P < 0.001$), MET index (β = 0.356, $P < 0.001$), and activity class (β = 0.418, $P < 0.001$) were positively associated with total recovery. Body fat percentage (β = −0.343, $P = 0.002$) and BMI (β = −0.309, $P = 0.001$) were negatively associated whereas VO_{2max} was positively associated with 24-h recovery index (β = 0.331, $P = 0.010$). MET index ($P = 0.414$) and activity class ($P = 0.151$) were not associated with 24-h recovery index.

Because the age range of the participants was relatively small and adjustment for age changed the results very minimally, the age-adjusted results are not shown. Adjustments for alcohol consumption, working time, or sleeping time influenced the results only minimally or modestly (Table 3). Adjustments for alcohol most influenced the associations of VO_{2max} with the stress and recovery variables. The results are presented in greater detail in Table 3.

A latent factor variable (Figure 1) was formed from body fat percentage, BMI, VO_{2max}, MET index, and activity class because these variables correlated significantly. The latent variable was a significant explanatory variable for all of the stress and recovery variables except RMSSD. It explained total recovery best at 30.1% of its variance. Among stress variables, the variance of total stress was best explained (27.5%) by the latent factor, which also explained 14.1% of the variance of work stress. The estimated model fit to the data well (χ^2 (35) = 41.09, $P = 0.22$, CFI = 0.99, TLI = 0.98, RMSEA = 0.046, SRMR = 0.06), and all the modification indices were lower than 4, which indicated that were no additional parameters that would have increased the fit of the model for the analysis.

In addition, objectively and subjectively measured stress levels were significantly associated (Table 4). HRV-based work stress (β = 0.272, $P = 0.003$) and total stress (β = 0.304, $P = 0.001$) explained the variation in total score of the BBI questionnaire. Adjustment for age changed the results only minimally, but after adjustment for body fat percentage, associations between work stress and the BBI total score did not persist.

Discussion

The results of this study showed that there were significant associations among PA, CRF, body composition, and novel HRV-based levels of stress and recovery in real life on workdays. Greater PA level, better CRF, and more favorable body composition were associated with lower stress levels during working hours as well as with lower stress levels and higher recovery levels throughout the whole day. Better recovery at night was associated with better CRF and a more favorable body composition. Additionally, the relationship between objectively measured stress and self-reported burnout symptoms was significant, and further analysis showed that body composition explained it in part.

The results of the present study are mainly in line with those of earlier studies that used traditional HRV measures. Favorable HRV profiles may be related to PA and CRF [15,16] while stress appears to be linked with reduced leisure-time PA [41] and lower physical fitness [2,42]. Earlier studies have proposed that fit individuals would show attenuated physiological reactivity to psychological stressors compared with sedentary individuals [43,44]. A more recent meta-analytic review by Forcier et al. [2] also provided support for the cross-adaptation hypothesis and suggested that fitness training may increase the ability of cardiovascular systems to control responses to acute stressors and also speed cardiovascular recovery from stress.

The present study found that among men, unfavorable body composition was associated with higher objective stress and lower recovery. According to previous studies that have examined stress as a subjective experience, the association between mental stress and body composition has been inconsistent because evidence both supports [45-49] and refutes [50-53] it. Additionally, the results suggested that body fat percentage explained part of the association between objectively and subjectively measured levels of stress, indicating that body fat percentage affects both physiological stress and subjective experience of stress among men. However, a previous study by Nyberg et al. [46] found that the relationship between stress and unfavorable body composition may not be linear. In an analysis of pooled European data (n = 161,746), both weight gain and weight loss were associated with the onset of job strain so that the cross-sectional association between job strain and BMI formed a 'U'-shaped curve [46].

The results showed that PA level was not associated with night-time recovery, although regular PA has consistently been associated with better sleep [54]. However, previous findings indicate that PA in the evening may delay the beginning of recovery. Physical fitness may have a role in recovery of HR and HRV after exercise, as could be seen even between trained and highly trained subjects, so that the recovery takes 60–90 min longer in trained subjects [55]. Recovery of HRV also depends on type, intensity, and duration of exercise [56]. In the study of Myllymäki et al. [57], a late-night exercise caused higher HR during the first three sleeping hours of an exercise day compared to a control day. Mischler et al. [58] reported that prolonged exercise had similar effects on HR during sleep. In addition to these effects of exercise on HR, HRV might decrease during the activity and, for instance, high-intensity exercises reduce HRV for 30–60 min afterward in trained and highly trained subjects [55,56]. Hynynen et al. [59] found that both moderate and heavy endurance exercise even in the daytime has an increasing effect

Table 3 The association of body composition, cardiorespiratory fitness, and physical activity with stress and recovery

	No adjustments			Alcohol adjusted			Working time adjusted			Sleeping time adjusted		
	β	S.E.	*P*	β	S.E.	*P*	β	S.E.	*P*	β	S.E.	*P*
Body fat%												
WS	0.306	0.108	0.005	0.288	0.114	0.012	0.315	0.114	0.006	0.313	0.115	0.006
TS	0.442	0.101	<0.001	0.405	0.107	<0.001	0.242	0.070	0.001	0.429	0.111	<0.001
SI	0.422	0.115	<0.001	0.395	0.108	<0.001	0.426	0.107	<0.001	0.425	0.107	<0.001
TR	−0.445	0.088	<0.001	−0.409	0.087	<0.001	−0.443	0.090	<0.001	−0.419	0.086	<0.001
RI	−0.343	0.113	0.002	−0.325	0.111	0.003	−0.338	0.103	0.001	−0.330	0.111	0.003
RMSSD	−0.293	0.123	0.017	−0.267	0.115	0.020	−0.285	0.109	0.009	−0.283	0.116	0.015
SB	−0.400	0.083	<0.001	−0.377	0.084	<0.001	−0.408	0.076	<0.001	−0.403	0.077	<0.001
RIS	−0.359	0.130	0.006	−0.328	0.127	0.010	−0.348	0.114	0.002	−0.351	0.125	<0.001
BMI												
WS	0.162	0.086	0.060	0.139	0.085	0.101	0.176	0.083	0.033	0.171	0.086	0.047
TS	0.272	0.093	0.003	0.210	0.090	0.020	0.268	0.086	0.002	0.251	0.095	0.009
SI	0.478	0.102	<0.001	0.447	0.105	<0.001	0.458	0.091	<0.001	0.482	0.097	<0.001
TR	−0.355	0.084	<0.001	−0.297	0.078	<0.001	−0.351	0.084	<0.001	−0.309	0.084	<0.001
RI	−0.309	0.093	0.001	−0.287	0.094	0.002	−0.298	0.087	0.001	−0.289	0.092	0.002
RMSSD	−0.304	0.106	0.004	−0.274	0.106	0.009	−0.290	0.097	0.003	−0.289	0.107	0.007
SB	−0.379	0.095	<0.001	−0.325	0.101	0.001	−0.395	0.087	<0.001	−0.384	0.092	<0.001
RIS	−0.395	0.102	<0.001	−0.358	0.105	0.001	−0.373	0.095	<0.001	−0.382	0.104	<0.001
VO_{2max}												
WS	−0.311	0.132	0.019	−0.282	0.147	0.055	−0.316	0.147	0.031	−0.317	0.145	0.029
TS	−0.416	0.126	0.001	−0.349	0.155	0.025	−0.411	0.145	0.004	−0.396	0.150	0.008
SI	−0.379	0.096	<0.001	−0.334	0.098	0.001	−0.377	0.094	<0.001	−0.375	0.095	<0.001
TR	0.465	0.111	<0.001	0.405	0.122	0.001	0.469	0.110	<0.001	0.429	0.107	<0.001
RI	0.331	0.128	0.01	0.302	0.139	0.030	0.319	0.133	0.016	0.307	0.143	0.032
RMSSD	0.262	0.125	0.037	0.222	0.125	0.076	0.247	0.123	0.045	0.242	0.130	0.062
SB	0.270	0.073	<0.001	0.145	0.091	0.113	0.283	0.073	<0.001	0.274	0.072	<0.001
RIS	0.294	0.125	0.019	0.243	0.131	0.063	0.275	0.121	0.023	0.276	0.136	0.042
MET index												
WS	−0.304	0.113	<0.001	−0.287	0.087	0.001	−0.308	0.087	<0.001	−0.311	0.086	<0.001
TS	−0.385	0.145	0.008	−0.349	0.084	<0.001	−0.384	0.083	<0.001	−0.368	0.086	<0.001
SI	−0.096	0.124	0.440	−0.065	0.105	0.535	−0.098	0.107	0.360	−0.099	0.105	0.343
TR	0.356	0.131	<0.001	0.316	0.102	0.002	0.355	0.095	<0.001	0.321	0.097	0.001
RI	0.138	0.173	0.414	0.120	0.140	0.390	0.135	0.136	0.319	0.122	0.141	0.389
RMSSD	0.058	0.165	0.723	0.032	0.152	0.834	0.054	0.147	0.713	0.046	0.151	0.761
SB	0.097	0.089	0.255	−0.017	0.081	0.835	0.102	0.074	0.172	0.101	0.069	0.141
RIS	0.074	0.173	0.670	0.038	0.159	0.810	0.067	0.150	0.654	0.063	0.158	0.690
Activity class												
WS	−0.326	0.102	0.001	−0.298	0.104	0.004	−0.330	0.107	0.002	−0.331	0.109	0.002
TS	−0.434	0.096	<0.001	−0.362	0.102	<0.001	−0.433	0.105	<0.001	−0.424	0.108	<0.001
SI	−0.222	0.113	0.048	−0.175	0.115	0.128	−0.224	0.115	0.051	−0.225	0.114	0.049
TR	0.418	0.097	<0.001	0.336	0.090	<0.001	0.417	0.098	<0.001	0.400	0.101	<0.001
RI	0.175	0.122	0.151	0.146	0.119	0.221	0.172	0.121	0.154	0.164	0.126	0.191

Table 3 The association of body composition, cardiorespiratory fitness, and physical activity with stress and recovery *(Continued)*

RMSSD	0.090	0.120	0.453	0.047	0.116	0.684	0.086	0.116	0.459	0.082	0.112	0.505
SB	0.237	0.106	0.025	0.082	0.095	0.390	0.241	0.107	0.024	0.239	0.106	0.024
RIS	0.132	0.129	0.305	0.076	0.125	0.544	0.127	0.125	0.311	0.125	0.132	0.343

Standardized estimate (β), standard error (S.E.), and *P* value for body fat%, BMI, VO_{2max}, MET index, and activity class in relation to Firstbeat stress and recovery variables (work stress [WS], total stress [TS], stress index [SI], total recovery [TR], recovery index 24 h [RI], RMSSD, stress balance [SB], and recovery index sleep [RIS]).

on HR and decreasing effect on HRV during sleep in a dose–response manner.

Subjective methods were used to assess the level of PA. The MET index was based on a detailed retrospective interview. This index correlated significantly with measured VO_{2max} values, supporting its validity to assess the level of PA. Subjective assessment may include some reporting bias; however, although the method undertaken was not objective, it had the advantage of taking several months of subjective data into account. The other method was self-reported activity class, which is regularly reported before the HRV measurement by Bodyguard.

One limitation of the present study is that the effect of different intensities of PA was not investigated; however, both light and moderate to vigorous leisure-time activity are related to lower likelihood of burnout [41]. Another limitation is that fat distribution was not taken into account, even though, according to earlier studies, it may have a role in relation to the HRV profile [19,60]. The nature of work in today's society is rather complex, including inexact and variable working hours and a lack of precise division between work time and leisure time, which causes difficulties in determining the level of HRV-based stress during exact working hours.

The current results cannot be generalized to women because the study population consisted of both physically inactive and active young male employees, who were not heavy drinkers or on regular medication. This population was ideal for this study because alcohol intake, diseases, and medications influence ANS [8]. The effect of possible alcohol intake on HRV was taken into account in the analyses. The fact that our study population consisted of young employees who are still establishing their careers highlights the importance of the findings.

Stress can be explained through several biological processes, such as the inflammatory, dopaminergic, and neuroendocrine systems [61]. However, in the present study, the measurement method for stress and recovery

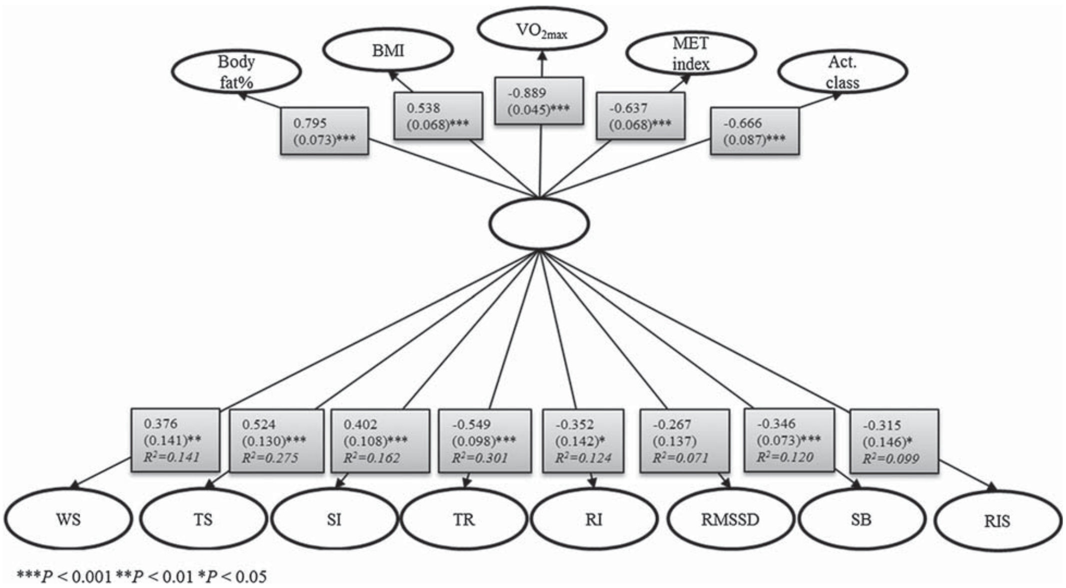

Figure 1 The variance of stress and recovery accounted for by physical activity, cardiorespiratory fitness, and body composition. The factor loadings (standardized estimate and S.E.) of body fat%, BMI, VO_{2max}, MET index, activity class, and the factor loadings (including R^2) for Firstbeat variables: work stress (WS), total stress (TS), stress index (SI), total recovery (TR), recovery index 24 h (RI), RMSSD, stress balance (SB), and recovery index sleep (RIS).

Table 4 Stress and recovery in relation to the Bergen Burnout Inventory total scores

	β	S.E.	P
Work stress	0.272	0.091	0.003
Total stress	0.304	0.095	0.001
Stress index	−0.080	0.118	0.500
Total recovery	−0.170	0.092	0.065
Recovery index (24 h)	−0.036	0.109	0.741
RMSSD	−0.009	0.101	0.925
Stress balance	−0.006	0.092	0.947
Recovery index (sleep)	−0.014	0.112	0.898

Standardized estimate (β), standard error (S.E.) and *P*-value.

was based on HR and HRV, which are affected by the ANS. Stressful situations result in accentuated sympathovagal antagonism, which may be explained by the interaction of acetylcholine and norepinephrine; consequently, HR may become remarkably unstable [62]. The findings of Tulppo et al. [62] suggest that traditional measures of HRV are not specific for measurement of accentuated sympathovagal interaction. The Firstbeat Analysis Server program connects information from these traditional measures of HRV, HR, and respiratory variables in the determination of stress and recovery states from individual HR and HRV values, but it does not separate eustress from distress.

Conclusions

This study used special HR- and HRV-based indicators of stress and recovery and found that PA, CRF, and body composition were associated with these indicators on workdays. On one hand, detailed interview-based MET index and self-reported activity class, and on the other hand, body fat percentage and BMI, associated rather similarly with the indicators of stress and recovery. This suggests that easily collected self-reported activity class and BMI can be used as indicators of PA and body composition in clinical work. The current findings support the usability of the objective indicators of stress (work stress and total stress) as they were associated with self-reported occupational burnout symptoms. Overall, the results support the usability of this HRV-based method in the evaluation of stress and recovery in line with some previous findings supporting its validity and reliability [25,63].

Competing interests

Rusko H. is a stockowner in Firstbeat Technologies Ltd. He did not contribute to writing the conclusions of the study. The other authors declare that they have no competing interests.

Authors' contributions

Study conception and design: TT, SM, AT, MR, JK, MK, UK. Acquisition of data: TT, SM, MR, TL, UK. Analysis and interpretation of data: TT, SM, AT, MR, TL, JK, MK, HR, UK. Statistical analysis: TT, AT. Drafting the manuscript: TT. Critical revision of the manuscript for important intellectual content: TT, SM, AT, MR, TL, JK, MK, HR, UK. Final approval of the version to be published: TT, SM, AT, MR, TL, JK, MK, HR, UK. Obtained funding: TT, JK, MK, UK. Administrative, technical, or material support: MK, UK.

Acknowledgements

The Body & Future Health study was supported by the SalWe Research Program for Mind and Body (Tekes - the Finnish Funding Agency for Technology and Innovation grant 1104/10). The FitFatTwin study was supported by the Finnish Ministry of Education and Culture. Kaprio J. and the Finnish twin studies have been supported by the Academy of Finland (grants # 265240, 263278, 264146). T. Teisala's work was supported by a personal grant from the Juho Vainio Foundation.

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Received: 21 February 2014 Accepted: 9 April 2014
Published: 18 April 2014

References

1. Gerber M, Pühse U: **Do exercise and fitness protect against stress-induced health complaints? A review of the literature.** *Scand J Public Health* 2009, **37**(Suppl 8):801–819.
2. Forcier K, Stroud LR, Papandonatos GD, Hitsman B, Reiches M, Krishnamoorthy J, Niaura R: **Links between physical fitness and cardiovascular reactivity and recovery to psychological stressors: a meta-analysis.** *Health Psychol* 2006, **25**(Suppl 6):723–739.
3. Tulppo MP, Hautala AJ, Mäkikallio TH, Laukkanen RT, Nissilä S, Hughson RL, Huikuri HV: **Effects of aerobic training on heart rate dynamics in sedentary subjects.** *J Appl Physiol* 2003, **95**(Suppl 1):364–372.
4. Sothmann MS, Buckworth J, Claytor RP, Cox RH, White-Welkley JE, Dishman RK: **Exercise training and the cross-stressor adaptation hypothesis.** *Exerc Sport Sci Rev* 1996, **24**(Suppl 1):267–288.
5. Dishman RK, Nakamura Y, Garcia ME, Thompson RW, Dunn AL, Blair SN: **Heart rate variability, trait anxiety, and perceived stress among physically fit men and women.** *Int J Psychophysiol* 2000, **37**(Suppl 2):121–133.
6. Reed MJ, Robertson CE, Addison PS: **Heart rate variability measurements and the prediction of ventricular arrhythmias.** *QJM* 2005, **98**(Suppl 2):87–95.
7. McMillan DE: **Interpreting heart rate variability sleep/wake patterns in cardiac patients.** *J Cardiovasc Nurs* 2002, **17**(Suppl 1):69–81.
8. Acharya UR, Joseph KP, Kannathal N, Lim CM, Suri JS: **Heart rate variability: a review.** *Med Bio Eng Comput* 2006, **44**:1031–1051.
9. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology: **Heart rate variability: standards of measurement, physiological interpretation and clinical use.** *Circulation* 1996, **93**(Suppl 5):1043–1065.
10. Malliani A, Pagani M, Lombardi F, Gerutti S: **Cardiovascular neural regulation explored in the frequency domain.** *Circulation* 1991, **84**(Suppl 2):482–492.
11. Vanderlei LCM, Pastre CM, Hoshi RA, Carvalho TD, Godoy MF: **Basic notions of heart rate variability and its clinical applicability.** *Rev Bras Cir Cardiovasc* 2009, **24**(Suppl 2):205–217.
12. Pumprla J, Howorka K, Groves D, Chester M, Nolan J: **Functional assessment of heart rate variability: physiological basis and practical applications.** *Int J Cardiol* 2002, **84**(Suppl 1):1–14.
13. Chandola T, Heraclides A, Kumari M: **Psychophysiological biomarkers of workplace stressors.** *Neurosci Biobehav Rev* 2010, **35**(Suppl 1):51–57.
14. Pichot V, Roche F, Denis C, Garet M, Duverney D, Costes F, Barthélémy J-C: **Interval training in elderly men increases both heart rate variability and baroreflex activity.** *Clin Auton Res* 2005, **15**(Suppl 2):107–115.

15. Jurca R, Church TS, Morss GM, Jordan AN, Earnest CP: **Eight weeks of moderate-intensity exercise training increases heart rate variability in sedentary postmenopausal women.** *Am Heart J* 2004, **147**(Suppl 5):8–15.
16. Pober DM, Braun B, Freedson PS: **Effects of a single bout of exercise on resting heart rate variability.** *Med Sci Sports Exerc* 2004, **36**(Suppl 7):1140–1148.
17. Rennie KL, Hemingway H, Kumari M, Brunner E, Malik M, Marmot M: **Effects of moderate and vigorous physical activity on heart rate variability in a British study of civil servants.** *Am J Epidemiol* 2003, **158**(Suppl 2):135–143.
18. Buchheit M, Gindre C: **Cardiac parasympathetic regulation: respective associations with cardiorespiratory fitness and training load.** *Am J Physiol Heart Circ Physiol* 2006, **291:**451–458.
19. Gao YY, Lovejoy JC, Sparti A, Bray GA, Keys LK, Partington C: **Autonomic activity assessed by heart rate spectral analysis varies with fat distribution in obese women.** *Obes Res* 2012, **4**(Suppl 1):55–63.
20. Jeong AK, Yong-Gyu P, Kyung-Hwan C, Myung-Ho H, Hee-Chul H, Youn-Seon C, Dokyung Y: **Heart rate variability and obesity indices: emphasis on the response to noise and standing.** *J Am Board Fam Pract* 2005, **18**(Suppl 2):97–103.
21. Zahorska-Markiewicz B, Kuagowska E, Kucio C, Klin M: **Heart rate variability in obesity.** *Int J Obes* 1993, **17**(Suppl 1):21–23.
22. Rissanen P, Franssila-Kallunki A, Rissanen A: **Cardiac parasympathetic activity is increased by weight loss in healthy obese women.** *Obes Res* 2001, **9**(Suppl 10):637–643.
23. Martinmäki K, Rusko H, Kooistra L, Kettunen J, Saalasti S: **Intraindividual validation of heart rate variability indexes to measure vagal effects on hearts.** *Am J Physiol Heart Circ Physiol* 2006, **290:**640–647.
24. **Firstbeat Technologies Ltd.** www.firstbeat.com.
25. Uusitalo A, Mets T, Martinmäki K, Mauno S, Kinnunen U, Rusko H: **Heart rate variability related to effort at work.** *Appl Ergonomics* 2011, **42**(Suppl 6):830–838.
26. **International standard randomized controlled trial number register.** www.controlled-trials.com/ISRCTN92130721/kujala.
27. Saalasti S: **Neural networks for heart rate time series analysis.** In *PhD Thesis*. Finland, Jyväskylä Studies in Computing 33, Jyväskylä: Department of Mathematical Information Technology; University of Jyväskylä; 2003.
28. Kettunen J, Saalasti S, inventors; Firstbeat Technologies Ltd, assignee: *Procedure for Deriving Reliable Information on Respiratory Activity from Heart Period Measurement.*: United States patent US 20050209521A1; 2005.
29. Kettunen J, Saalasti S, inventors; Firstbeat Technologies Ltd, assignee: *Procedure for Detection of Stress by Segmentation and Analyzing Heart Beat Signal*: United States patent US 007330752B2; 2008.
30. **White papers.** http://www.firstbeat.com/physiology/white-papers.
31. Achten J, Jeukendrup AE: **Heart rate monitoring.** *Sports Med* 2003, **33**(Suppl 7):517–538.
32. Salmela-Aro K, Näätänen P, Nurmi J-E: **The role of work-related personal projects during two burnout interventions: a longitudinal study.** *Work Stress* 2004, **18**(Suppl 3):208–230.
33. Näätänen P, Aro A, Matthiesen S, Salmela-Aro K: *Bergen Burnout Indicator 15.* Helsinki: Edita; 2003.
34. Waller K, Kaprio J, Kujala UM: **Associations between long-term physical activity, waist circumference and weight gain: a 30-year longitudinal twin study.** *Int J Obes* 2007, **32**(Suppl 2):353–361.
35. Lakka TA, Salonen JT, The physical activity questionnaires of the Kuopio Ischemic Heart Disease Study (KIHD): **A collection of physical activity questionnaires for health related research.** *Med Sci Sports Exerc* 1997, **29:**46–58.
36. Ross RM, Jackson AS: *Exercise Concepts, Calculations, and Computer Applications.* Carmel, Indiana: Benchmark press; 1990.
37. **EPOC based training effect assessment.** www.firstbeat.fi/userData/firstbeat/download/white_paper_training_effect.pdf.
38. Andersen KL, Shephard RJ, Denolin H, Varnauskas E, Masironi R: *Fundamentals of Exercise Testing.* Geneva: World Health Organization; 1971.
39. Muthén LK, Muthén BO: *Mplus User's Guide.* 7th edition. Los Angeles: CA: Muthén & Muthén; 1998–2012.
40. Hu LT, Bentler PM: **Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives.** *Struct Equation Modeling* 1999, **6**(Suppl 1):1–55.
41. Jonsdottir IH, Rödjer L, Hadzibajramovic E, Börjesson M, Ahlborg G: **A prospective study of leisure-time physical activity and mental health in Swedish health care workers and social insurance officers.** *Prev Med* 2010, **51**(Suppl 5):373–377.
42. Holtermann A, Mortensen OS, Burr H, Søgaard K, Gyntelberg F, Suadicani P: **Physical fitness and perceived psychological pressure at work: 30-year ischemic heart disease and all-cause mortality in the copenhagen male study.** *J Occup Env Med* 2011, **53**(Suppl 7):743–750.
43. Anshel MH: **Effect of chronic aerobic exercise and progressive relaxation on motor performance and affect following acute stress.** *Behav Med* 1996, **21**(Suppl 4):186–196.
44. van Doornen LJ, de Geus EJ: **Aerobic fitness and the cardiovascular response to stress.** *Psychophysiol* 1989, **26**(Suppl 1):17–28.
45. Kitaoka-Higashiguchi K, Morikawa Y, Miura K, Sakurai M, Ishizaki M, Kido T, Naruse Y, Nakagawa H: **Burnout and risk factors for arteriosclerotic disease: follow-up study.** *J Occup Health* 2009, **51**(Suppl 2):123–131.
46. Nyberg ST, Heikkilä K, Fransson EI, Alfredsson L, De Bacquer D, Bjorner JB, Bonenfant S, Borritz M, Burr H, Casini A, Clays E, Dragano N, Erbel R, Geuskens GA, Goldberg M, Hooftman WE, Houtman IL, Jöckel KH, Kittel F, Knutsson A, Koskenvuo M, Leineweber C, Lunau T, Madsen IEH, Magnusson Hanson LL, Marmot MG, Nielsen ML, Nordin M, Oksanen T, Pentti J, *et al*: **Job strain in relation to body mass index: pooled analysis of 160 000 adults from 13 cohort studies.** *J Intern Med* 2012, **272:**65–73.
47. Block JP, He Y, Zaslavsky AM, Ding L: **Psychosocial stress and change in weight among US adults.** *Am J Epidemiol* 2009, **170**(Suppl 2):181–192.
48. Brunner EJ, Chandola T, Marmot MG: **Prospective effect of job strain on general and central obesity in the Whitehall II Study.** *Am J Epidemiol* 2007, **165**(Suppl 7):828–837.
49. Hannerz H, Albertsen K, Nielsen ML, Tüchsen F, Burr H: **Occupational factors and 5-year weight change among men in a danish national cohort.** *Health Psychol* 2004, **23**(Suppl 3):283–288.
50. Armon G, Shirom A, Berliner S, Shapira I, Melamed S: **A prospective study of the association between obesity and burnout among apparently healthy men and women.** *J Occup Health Psychol* 2008, **13**(1):43–57.
51. Ostry AS, Radi S, Louie AM, LaMontagne AD: **Psychosocial and other working conditions in relation to body mass index in a representative sample of Australian workers.** *BMC Public Health* 2006, **6**(Suppl 1):53–61.
52. Overgaard D, Gyntelberg F, Heitmann BL: **Psychological workload and body weight: is there an association? A review of the literature.** *Occup Med* 2004, **54**(Suppl 1):35–41.
53. Niedhammer I, Goldberg M, Leclerc A, David S, Bugel I, Landre M-F: **Psychosocial work environment and cardiovascular risk factors in an occupational cohort in France.** *J Epidemiol Community Health* 1998, **52**(Suppl 2):93–100.
54. Driver HS, Taylor SR: **Exercise and sleep.** *Sleep Med Rev* 2000, **4**(Suppl 4):387–402.
55. Seiler S, Haugen O, Kuffel E: **Autonomic recovery after exercise in trained athletes: intensity and duration effects.** *Med Sci Sports Exerc* 2007, **39** (Suppl 8):1366–1373.
56. Kaikkonen P, Rusko H, Martinmäki K: **Post-exercise heart rate variability of endurance athletes after different high-intensity exercise interventions.** *Scand J Med Sci Sports* 2008, **18**(Suppl 4):511–519.
57. Myllymäki T, Kyröläinen H, Savolainen K, Hokka L, Jakonen R, Juuti T, Martinmäki K, Kaartinen J, Kinnunen M-L, Rusko H: **Effects of vigorous late-night exercise on sleep quality and cardiac autonomic activity.** *J Sleep Res* 2011, **20:**146–53.
58. Mischler I, Vermorel M, Montaurier C, Mounier R, Pialoux V, Péquignot J-M, Cottet-Emard J-M, Coudert J, Fellmann N: **Prolonged daytime exercise repeated over 4 days increases sleeping heart rate and metabolic rate.** *Can J Appl Physiol* 2003, **28**(Suppl 4):616–629.
59. Hynynen E, Vesterinen V, Rusko H, Nummela A: **Effects of moderate and heavy endurance exercise on nocturnal HRV.** *Int J Sports Med* 2010, **31** (Suppl 6):428–432.
60. Grassi G, Dell'Oro R, Facchini A, Trevano FQ, Bolla GB, Mancia G: **Effect of central and peripheral body fat distribution on sympathetic and baroreflex function in obese normotensives.** *J Hypertens* 2004, **22**(Suppl 12):2363–2369.
61. Hamer M: **Psychosocial stress and cardiovascular disease risk: the role of physical activity.** *Psychosom Med* 2012, **74**(Suppl 9):896–903.
62. Tulppo MP, Mäkikallio TH, Seppänen T, Airaksinen JK, Huikuri HV: **Heart rate dynamics during accentuated sympathovagal interaction.** *AJP* 1998, **274**(Suppl 3):H810–H816.
63. Hynynen E, Konttinen N, Kinnunen U, Kyröläinen H, Rusko H: **The incidence of stress symptoms and heart rate variability during sleep and orthostatic test.** *Eup J Appl Physiol* 2011, **111**(Suppl 5):733–741.

doi:10.1186/1745-6673-9-16
Cite this article as: Teisala *et al.*: Associations of physical activity, fitness, and body composition with heart rate variability–based indicators of stress and recovery on workdays: a cross-sectional study. *Journal of Occupational Medicine and Toxicology* 2014 **9**:16.

IV

PHYSICAL ACTIVITY, BODY MASS INDEX AND HEART RATE VARIABILITY-BASED STRESS AND RECOVERY IN 16 275 FINNISH EMPLOYEES: A CROSS-SECTIONAL STUDY

by

Föhr, T., Pietilä, J., Helander, E., Myllymäki, T., Lindholm, H., Rusko, H. & Kujala, U. M. 2016

BMC Public Health 16:701, doi: 10.1186/s12889-016-3391-4

Föhr et al. BMC Public Health (2016) 16:701
DOI 10.1186/s12889-016-3391-4

BMC Public Health

RESEARCH ARTICLE Open Access

Physical activity, body mass index and heart rate variability-based stress and recovery in 16 275 Finnish employees: a cross-sectional study

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Abstract

Background: Physical inactivity, overweight, and work-related stress are major concerns today. Psychological stress causes physiological responses such as reduced heart rate variability (HRV), owing to attenuated parasympathetic and/or increased sympathetic activity in cardiac autonomic control. This study's purpose was to investigate the relationships between physical activity (PA), body mass index (BMI), and HRV-based stress and recovery on workdays, among Finnish employees.

Methods: The participants in this cross-sectional study were 16 275 individuals (6863 men and 9412 women; age 18–65 years; BMI 18.5–40.0 kg/m^2). Assessments of stress, recovery and PA were based on HRV data from beat-to-beat R-R interval recording (mainly over 3 days). The validated HRV-derived variables took into account the dynamics and individuality of HRV. Stress percentage (the proportion of stress reactions, workday and working hours), and stress balance (ratio between recovery and stress reactions, sleep) describe the amount of physiological stress and recovery, respectively. Variables describing the intensity (i.e. magnitude of recognized reactions) of physiological stress and recovery were stress index (workday) and recovery index (sleep), respectively. Moderate to vigorous PA was measured and participants divided into the following groups, based on calculated weekly PA: inactive (0 min), low (0 < 150 min), medium (150–300 min), and high (>300 min). BMI was calculated from self-reported weight and height. Linear models were employed in the main analyses.

Results: High PA was associated with lower stress percentages (during workdays and working hours) and stress balance. Higher BMI was associated with higher stress index, and lower stress balance and recovery index. These results were similar for men and women ($P < 0.001$ for all).

Conclusion: Independent of age and sex, high PA was associated with a lower amount of stress on workdays. Additionally, lower BMI was associated with better recovery during sleep, expressed by a greater amount and magnitude of recovery reactions, which suggests that PA in the long term resulting in improved fitness has a positive effect on recovery, even though high PA may disturb recovery during the following night. Obviously, several factors outside of the study could also affect HRV-based stress.

Keywords: Body mass index, Heart rate variability, Physical activity, Physiological stress, Stress, Stress assessment

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Background

Physical activity (PA) is known to have positive effects on health [1, 2]. Routine PA reduces stress and enhances psychological wellbeing, which is particularly important for the prevention and management of cardiovascular disease, among other chronic diseases [3]. Regular PA is known to reduce the risk of many adverse health outcomes. Some PA is better than none; however, for most health outcomes, additional benefits are achieved if the amount of PA increases through higher intensity, greater frequency, and/or longer duration. According to the 2008 Physical Activity Guidelines for Americans, most health benefits occur with at least 150 total minutes of moderate intensity or at least 75 min of vigorous intensity aerobic PA per week. However, additional benefits occur with more PA [4, 5]. In addition to the beneficial effects of PA on physical health, these guidelines are also relevant for mental health [6]. Although leisure-time PA has increased among Finnish adults [7], physical inactivity is a major problem and risk for health, in all countries. Furthermore, physical inactivity is associated with being overweight [8] and the current rate of overweight adults worldwide has been described as an epidemic or even a pandemic. This situation is a major public health risk because being overweight is associated with diseases including coronary heart disease, stroke, diabetes and cancer [9].

Together with physical inactivity and overweight, stress at work is a major public health risk. It may even lead to cardiovascular disease [10] without complete recovery [11]. Stress has been shown to reduce participation in leisure-time PA [12, 13]. Furthermore, workplace stress may predict a future increased risk of insufficient PA [14]. Normal weight is associated with good self-reported subjective health [15], including low stress levels [16, 17]. Evidence suggests that psychosocial stress is associated with the development of adiposity [18]. However, according to previous studies, the association between subjective stress and body composition is inconsistent, with evidence both supporting [16, 19] and refuting [20, 21] the idea that stress is associated with adiposity. A recent systematic review reported that the associations of psychosocial factors at work with weight-related outcomes were weak and somewhat inconsistent [22].

Psychological stress causes sympathetic responses in the autonomic nervous system (ANS), such as reduced heart rate variability (HRV) [23]. HRV refers to the variation in intervals between heartbeats and reflects cardiac autonomic modulation. Physiological stress can be defined as an increased body activation level, when sympathetic activity dominates the ANS and parasympathetic activation is low. Stress is associated with reduced HRV, owing to attenuated parasympathetic and/or increased sympathetic activity in cardiac autonomic control. Recovery refers to a reduced body activation level, when parasympathetic activation dominates the ANS over sympathetic activity [24–26]. HRV analysis can be used as a complementary tool to assess general health [27]. HRV analysis during sleep has the potential to explore the sleeping brain, with possible implications for mental health [28]. Previous HRV-studies have mainly used traditional time-domain and frequency-domain measures of HRV, such as root mean square of successive R-R intervals (RMSSD) and the ratio of low frequency power to high frequency power (LF/HF ratio). The traditional measures of HRV represent the average level of the autonomic activity over a period of the time. Cardiac autonomic activity is very dynamic and varies during the day depending on stress, recovery and PA. Therefore, the usability of the traditional measures of HRV is limited in real-life conditions. Additionally, these measures are very individual which further limits their usability in stress assessment and clinical work. However, it is also possible to provide applied heart rate (HR) and HRV-derived stress and recovery variables that take into account the dynamic changes in autonomic activity and individuality of HRV including information that is difficult to obtain from traditional measures of HRV.

The majority of previous studies on the association of PA with stress have used subjective assessment methods or traditional measures of HRV in the assessment of stress. The previous studies support the association of PA with increased HRV [29, 30]. However, accurate and objective methods are needed to reliably assess PA, as well as to assess HRV-based stress and recovery in real-life. By utilizing a method that acknowledges the dynamics and individuality in HRV in real-life, the aim of this study was to investigate the extent to which PA and BMI are associated with HRV-based indicators of stress and recovery on workdays. The study was conducted among 16 275 Finnish employees who had participated in beat-to-beat R-R interval recording as a part of lifestyle counseling between 2007 and 2015. More specifically, accounting for age and sex, we investigated the prevalence of stress and recovery according to the participants' objectively measured PA level and self-reported body mass index (BMI). Uniqueness of the present study is in the individual and dynamic method used in the assessment of physiological stress and recovery.

Methods

Study design and participants

This cross-sectional study investigated the amount and intensity of objective HRV-based stress and recovery on workdays in a real-life sample of 16 275 Finnish employees (6863 men and 9412 women; age 18–65 years; BMI 18.5–40.0 kg/m^2). The participants nonselectively represent a cross-section of typical Finnish employees including both manual and non-manual labour employees.

The majority of the participants were apparently healthy without chronic diseases. The exclusion criteria for participation in the R-R interval recordings included severe cardiac disease, very high blood pressure (≥180/100 mmHg), type 1 or 2 diabetes with autonomic neuropathy, severe neurological disease, fever or other acute disease, and BMI >40 kg/m^2. These exclusion criteria represented by the analysis software manufacturer are presented in detail previously [31]. The characteristics of the participants are presented in Table 1.

Data collection

The novel methodology used to determine the participants' stress, recovery and level of weekly PA, was based on HRV data from beat-to-beat R-R interval recordings. These recordings were voluntarily performed on employees as a part of the preventive occupational health care programs provided by their employers between 2007 and 2015. The clinical purpose of these measurements is presented comprehensively in a previous paper by Mutikainen et al. [31]. The data recordings used in the previous study were gathered between 2007 and 2013, with a study population size of 9554. These data were used in the present study, supplemented with recordings from 2014 to 2015. The study had a further inclusion criterion of a minimum of 4.5 h beat-to-beat R-R interval recording during sleep after a workday. Another inclusion criterion was the availability of R-R interval data, including at least one workday (≥4 h of work) and one day off, with a measurement period of 16–30 h/day (from wake-up to wake-up). Participants who had consumed alcohol on the monitoring days were excluded. Information about workdays, working hours, days off and sleep periods was obtained from diaries that the participants were requested to keep during the measurement period. The analyzed data consisted of successfully recorded (measurement error <15 % and <30-min recording break) days. The flow of the participants included in the analysis is presented in Fig. 1.

HRV-based assessment of PA, stress and recovery

Ambulatory beat-to-beat R-R interval data were used to determine the amount and intensity of PA, stress and recovery. Using the Firstbeat Bodyguard device (Firstbeat Technologies Ltd., Jyväskylä, Finland), real-life R-R interval data were recorded, usually over 3 days (typically two workdays and one day off) and analyzed using Firstbeat Analysis Server software (version 6.3, Firstbeat Technologies Ltd.), which included a powerful artifact detection and correction feature for irregular ectopic beats and signal noise. The software calculates HRV indices second-by-second using the short-time Fourier transform method, and calculates HR- and HRV-derived variables of respiration rate, oxygen consumption, on-off kinetics (increasing or decreasing HR), and parameters describing excess post-exercise oxygen consumption using neural networks. Thereafter, the software divides the measurement data into coherent data segments and categorizes these segments into different physiological states, such as PA of different intensities, stress and recovery [32–34], by taking into account individual characteristics (e.g. individual levels and scales of HR and HRV, and the individual relationships between HRV and autonomic control) [35]. The categorization of the data is described in Additional file 1: Table S1. More information about this analysis method is available in a paper by Firstbeat Technologies Ltd. [36].

Detection of stress and recovery variables

After data categorization, the HRV-based variables describing the amount and intensity of stress and recovery on workdays were detected. Stress percentages (i.e. proportions of stress reactions, during the day and during working hours) and stress balance (ratios between recovery and stress reactions during sleep) describe the amount of stress and recovery, respectively. The variables describing the intensity (i.e. magnitude of recognized reactions) of stress and recovery were stress index (during the day) and recovery index (during sleep), respectively. These variables and their calculations are presented in Additional file 1: Table S1. The correlation coefficient between two consecutive workdays varied from 0.74 to 0.88 for the traditional HRV variables, from 0.64 to 0.93 for HRV-derived variables of stress, and from 0.42 to 0.49 for HRV-derived variables of recovery during sleep.

Calculation of weekly PA

Background information about age, sex, self-reported height and weight, and self-reported PA class [37] modified from Ross and Jackson [38], was collected in

Table 1 Characteristics of the participants

Variable	All (n = 16275)			Men (n = 6863)			Women (n = 9412)		
	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max
Age	44.8 ± 9.9	18.0	65.0	44.5 ± 9.9	18.0	65.0	45.0 ± 9.9	18.0	65.0
Body mass index (kg/m^2)	26.0 ± 4.1	18.5	40.0	26.6 ± 3.5	18.6	40.0	25.5 ± 4.4	18.5	40.0
Self- reported activity class 0–10	4.8 ± 1.8	0.0	10.0	4.9 ± 1.9	0.0	10.0	4.8 ± 1.8	0.0	10.0
Physical activity (mins/week)	186 ± 227	0	2629	246 ± 258	0	2629	142 ± 189	0	1865

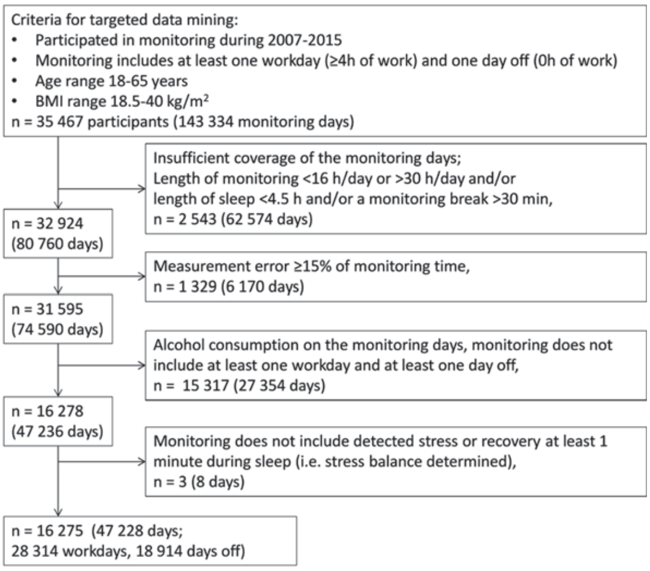

Fig. 1 Flow of the participants and measurement days included in the analysis (BMI, body mass index)

conjunction with R-R interval recordings using questionnaires. Background information was used to estimate maximal HR [39] and maximal VO_2 [40] which were then used in the estimation of VO_2. The maximal HR used for further calculations was corrected accordingly if a period with HR higher than the estimated maximal was found from the recording. From the second-by-second VO_2 estimations, each participant's mean VO_2 for each minute of the measurement day was calculated. The minute-by-minute VO_2 estimations were then converted to multiples of the resting metabolic rate (MET) by dividing the VO_2 values by 3.5. The total number of 1-min segments within the following thresholds: moderate PA 3 to <6 METs and vigorous PA ≥6 METs, during each measurement day (including days off), were calculated. Continuous bouts of PA lasting for ≥10 min were included in the estimation of weekly PA. These continuous bouts of PA were calculated separately for workdays and days off, and, if the measurement period included two or more workdays or days off, an average was calculated. The activity minutes score for each day (moderate PA minutes + vigorous PA minutes × 2) was calculated. Thereafter, the amount of PA was extrapolated using the following formula: PA minutes per week = (5 × mean workday activity score) + (2 × mean day-off activity score). These calculations have been previously described in more detail [31]. Based on the weekly PA minutes, the participants were divided into the following PA groups: inactive (0 min), low (0 < 150 min), medium (150–300 min) and high (>300 min).

Assessment of body composition

BMI was calculated from the self-reported weight and height (kg/m^2). The participants were then divided into the following groups: normal weight (18.5 to <25 kg/m^2), overweight (25 to <30 kg/m^2) and obese (30–40 kg/m^2).

Analysis

Data processing and statistical analysis were performed using R 3.2.2 version (R Foundation for Statistical Computing). P-values were two-sided and a p-value of <0.05 was considered statistically significant. Because of the size of the data, 99 % confidence intervals (CIs) were determined (Fig. 2) instead of conventional 95 % CIs.

The main outcome variables of the study were stress percentage and stress index, calculated for the whole day, stress percentage calculated for working hours, and stress balance and recovery index calculated for sleep. These variables were derived from the beat-to-beat R-R interval recordings on workdays. For a more detailed description of the variables see Additional file 1: Table S1. In addition, HR and traditional HRV parameters, including RMSSD and the LF/HF ratio, were calculated from the beat-to-beat R-R interval recordings on workdays. These variables were calculated separately for waking hours and sleep, and RMSSD was calculated using a 5-min window. If the measurement period of a subject included two or more workdays, an average was calculated and the mean values of the outcome variables were used in the analysis.

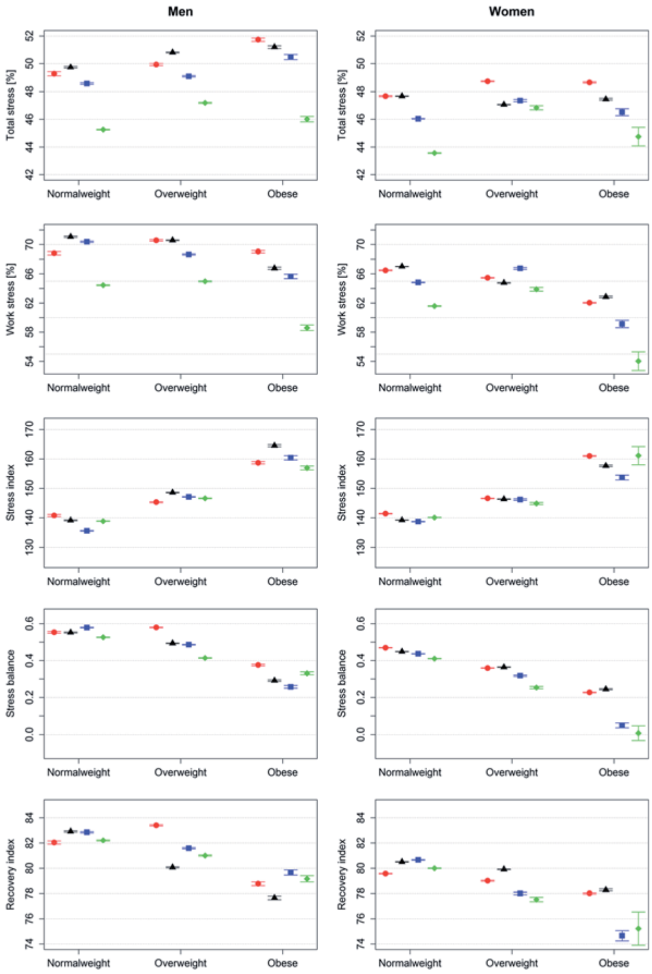

Fig. 2 Stress and recovery by physical activity and body mass index groups with age-controlled mean values and 99 % CIs for output variables. Physical activity groups: inactive (0 min/week), *red* ●; low (0 < 150 min/week), *black* ▲; medium (150–300 min/week), *blue* ■; high (>300 min/week), *green* ♦

For the descriptive statistics, the means and standard deviations of the outcome variables were calculated separately for men and women, and stratified based on PA, BMI and age. Differences in the outcome variables between PA, BMI and age groups were tested using the Kruskal-Wallis test. The results are shown in Additional file 2: Tables S2-S4. To show the effects of BMI and PA group on the HRV-based stress and recovery variables, the age-controlled mean values and 99 % CIs for the HRV-based stress and recovery variables, by BMI and PA group, are presented in Fig. 2.

Linear models were employed to study the effects of PA group, BMI and age on HRV-based stress and recovery variables. In the models, age and BMI were incorporated as continuous predictor variables and objectively measured PA group was incorporated as a categorical predictor variable. The models were generated separately for men and women. The reference value for age was set to 18 years and for BMI to 18.5 kg/m^2. A simple linear least squares regression model (procedure *lm* in R) was applied to predict the stress percentage during the day. As confirmed by visual inspection, the assumption of linear regression considering the normal distribution of the residuals was not fulfilled for stress percentage during working hours, stress index and recovery index. Thus, a Box-Cox transformation was applied on these dependent variables [41]. The Box-Cox coefficient was determined by maximizing the log-likelihood function and was rounded to two decimal places before transformation. Tobit regression model (procedure *vglm* using iteratively reweighted least squares in R) was applied for modeling stress balance with a fixed lower and upper limit of −1 and 1, respectively. The interactions of the predictors were not included in the final regression models because the coefficient of determination for the interaction models was only a few percentage points greater than for the simple models.

Results

The total number of workdays included in the analysis was 28 314, with measurements obtained from 16 275 participants (men 6863; women 9412). The participants' characteristics are shown in Table 1. The participants' mean age was 44.8 years (44.5 years for men; 45.0 years for women) and the mean BMI was 26.0 kg/m^2 (26.6 kg/m^2 for men; 25.5 kg/m^2 for women). The participants' mean self-reported activity class was 4.8 (4.9 for men; 4.8 for women) indicating that, on average, the participants were involved in PA 2–3 times per week and their total weekly PA was about 2 h. The mean weekly minutes of objective monitoring-based PA was 186 (246 for men; 142 for women). The mean weekly minutes of PA in the group of low PA was 78 for men and 74 for women, in the group of medium PA 222 for men and 215 for women, and in the group of high PA 545 for men and 496 for women. The number of participants in the PA, BMI, and age groups is presented in Additional file 3: Table S5.

Differences in outcome variables between PA groups (Additional file 2: Table S2) were statistically significant except for LF/HF ratio during waking hours and sleep, stress balance in men, and HR and stress balance in women. For both men and women, the high PA group had the highest RMSSD (during waking hours and during sleep) and recovery index, and the lowest stress percentage (during the day and during working hours) and stress index.

Differences in outcome variables between BMI groups were statistically significant for both men and women (Additional file 2: Table S2). Normal-weight individuals had the highest RMSSD (both during waking hours and during sleep), stress balance and recovery index, the lowest stress percentage during the day and the lowest stress index. Stress percentage during working hours was lowest in obese individuals.

In both sexes, differences in outcome variables were statistically significant between age groups, except for HR during sleep in women (Additional file 2: Table S3). The youngest age group (18–30 years) had the highest RMSSD (both during waking hours and during sleep), stress balance and recovery index, and the lowest stress index. Stress percentages during the day were lowest in the youngest age group in women, and in the oldest age group (51–65 years) in men. Stress percentages during working hours were lowest in the oldest age group in both sexes.

Figure 2 shows the effect of PA and BMI group on the stress and recovery variables with the effect of age controlled. The high PA group had the lowest mean stress percentage during the day and during working hours in all three BMI groups, after adjustment for age (Fig. 2). Mean stress index values increased as the BMI group changed from normal weight to overweight and overweight to obese, regardless of the PA group. In addition, regardless of the PA group, obese individuals had the lowest stress balance and recovery index.

The linear model results are shown in Table 2. Medium ($P < 0.05$) and high ($P < 0.001$) PA groups, lower BMI ($P < 0.001$), and older age ($P < 0.001$) were associated with lower stress percentages during the day. Medium ($P < 0.05$) and high ($P < 0.001$) PA level, higher BMI ($P < 0.001$), and older age ($P < 0.001$) were associated with lower stress percentages during working hours. Stress percentage results during the day and during working hours were similar for men and women. Higher BMI ($P < 0.001$) and older age ($P < 0.001$) were associated with higher stress index, both in men and in women. In addition, medium ($P < 0.01$) and high ($P < 0.01$) PA were associated with lower stress index in women.

Medium ($P < 0.01$) and high ($P < 0.001$) PA, and higher BMI ($P < 0.001$) were associated with lower stress balance, both in men and in women. Moreover, older age was associated with lower stress balance in men ($P < 0.001$). Higher BMI and older age were associated with lower recovery index, in men and in women ($P < 0.001$). BMI explained the highest proportion of variance in stress balance (2.2 % for men and 3.1 % for women) compared with PA and age.

Discussion

The purpose of this study was to investigate the amount and intensity of objective HRV-based stress and recovery on workdays. The sample group comprised 16 275 Finnish employees, who had participated in beat-to-beat R-R interval recording as a part of lifestyle counseling in the course of their everyday lives between 2007 and 2015. More specifically, the relationships between PA, BMI, and HRV-based stress and recovery were investigated. For both sexes, a high level of PA and lower BMI

Table 2 Results of the linear models

	Men					Women				
	Parameter Estimate	95 % CI Lower	Upper	*P* value	Variance explained (%)	Parameter Estimate	95 % CI Lower	Upper	*P* value	Variance explained (%)
Stress (%), 24 h [a]					2.356[h]					1.476 [h]
Intercept	52.3153	50.7730	53.8575	<0.001		50.0658	48.9790	51.1527	<0.001	
Age (18 years = 0)	−0.1263	−0.1600	−0.0926	<0.001	0.780[i]	−0.0869	−0.1151	−0.0587	<0.001	0.387 [i]
BMI (18.5 kg/m^2 = 0)	0.1541	0.0580	0.2502	0.002	0.144 [i]	0.0909	0.0264	0.1553	0.006	0.081 [i]
Physical activity level (inactive = 0)					1.586 [i]					1.050 [i]
Low physical activity class	0.3235	−0.6903	1.3372	0.53		−0.8892	−1.5471	−0.2313	0.008	
Medium physical activity class	−1.1405	−2.2144	−0.0667	0.04		−1.9539	−2.7608	−1.1470	<0.001	
High physical activity class	−3.9695	−5.0062	−2.9328	<0.001		−4.3772	−5.2620	−3.4923	<0.001	
Stress (%), working hours [b]					4.152 [h]					1.721 [h]
Intercept	807.3480	777.0476	837.6483	<0.001		677.8091	656.0738	699.5443	<0.001	
Age (18 years = 0)	−4.8729	−5.5355	−4.2103	<0.001	2.942 [i]	−2.66482	−3.22838	−2.10127	<0.001	0.905 [i]
BMI (18.5 kg/m^2 = 0)	−4.6640	−6.5515	−2.7766	<0.001	0.341 [i]	−4.54067	−5.82984	−3.25149	<0.001	0.504 [i]
Physical activity level (inactive = 0)					1.590 [i]					0.584 [i]
Low physical activity class	−5.5094	−25.4261	14.4073	0.59		−3.40975	−16.5664	9.746938	0.61	
Medium physical activity class	−24.7847	−45.8819	−3.6874	0.021		−17.9339	−34.0695	−1.79829	0.030	
High physical activity class	−85.2896	−105.6576	−64.9215	<0.001		−61.7878	−79.4833	−44.0923	<0.001	
Stress index, 24 h [c]					27.113 [h]					27.448 [h]
Intercept	1.2406	1.2403	1.2409	<0.001		1.2414	1.2412	1.2417	<0.001	
Age (18 years = 0)	0.0001	0.0001	0.0001	<0.001	21.992 [i]	0.0001	0.0001	0.0001	<0.001	19.655 [i]
BMI (18.5 kg/m^2 = 0)	0.0002	0.0001	0.0002	<0.001	3.819 [i]	0.0001	0.0001	0.0001	<0.001	3.031 [i]
Physical activity level (inactive = 0)					0.115 [i]					0.145 [i]
Low physical activity class	0.0002	0.0000	0.0004	0.024		−0.0001	−0.0003	0.0000	0.031	
Medium physical activity class	0.0000	−0.0002	0.0002	0.91		−0.0002	−0.0004	−0.0001	0.002	
High physical activity class	0.0001	−0.0001	0.0003	0.47		−0.0003	−0.0004	−0.0001	0.002	
Stress balance, sleep [e]					3.669 [h]					3.244 [h]
Intercept1	0.9975	0.9287	1.0663	<0.001		0.6166	0.5672	0.6661	<0.001	
Intercept2	−0.5292	−0.5503	−0.5082	<0.001		−0.5537	−0.5705	−0.5368	<0.001	
Age (18 years = 0)	−0.0066	−0.0081	−0.0052	<0.001	1.153 [i]	−0.0007	−0.0019	0.0006	0.31	0.006 [i]
BMI (18.5 kg/m^2 = 0)	−0.0273	−0.0315	−0.0231	<0.001	2.179 [i]	−0.0253	−0.0282	−0.0224	<0.001	3.080 [i]
Physical activity level (inactive = 0)					0.445 [i]					0.233 [i]
Low physical activity class	−0.0715	−0.1162	−0.0269	0.002		−0.0126	−0.0423	0.0172	0.41	

Table 2 Results of the linear models *(Continued)*

Medium physical activity class	−0.0799	−0.1272	−0.0326	<0.001		−0.0572	−0.0937	−0.0207	0.002	
High physical activity class	−0.1327	−0.1784	−0.0870	<0.001		−0.0822	−0.1222	−0.0421	<0.001	
Recovery index, sleep [f]					9.685 [h]					3.297 [h]
Intercept	592375.4298	573358.1497	611392.7100	<0.001		457913.8301	444648.7930	471178.8673	<0.001	
Age (18 years = 0)	−5092.7330	−5508.5947	−4676.8712	<0.001	7.753 [i]	−2100.7061	−2444.6430	−1756.7692	<0.001	1.501 [i]
BMI (18.5 kg/m^2 = 0)	−4825.0722	−6009.6783	−3640.4662	<0.001	0.921 [i]	−4038.5841	−4825.3668	−3251.8014	<0.001	1.065 [i]
Physical activity level (inactive = 0)					0.154 [i]					0.026 [i]
Low physical activity class	−19214.5686	−31714.7934	−6714.3437	0.003		1051.0555	−6978.4656	9080.5766	0.80	
Medium physical activity class	−6153.1124	−19394.2693	7088.0445	0.36		−4452.2347	−14299.7786	5395.3093	0.38	
High physical activity class	−9653.5430	−22437.0465	3129.9606	0.14		−5732.9247	−16532.4796	5066.6302	0.30	

BMI body mass index
[a] Linear regression
[b] Box-Cox linear regression using transformation coefficient of 1.62
[c] Box-Cox linear regression using transformation coefficient of −0.79
[e] Tobit regression
[f] Box-Cox linear regression using transformation coefficient of 3.18
[h] The proportion of variance explained by the whole model
[i] The proportion of variance explained by the predictor variable. Calculated as the difference between the proportion of variance explained by the whole model and the proportion of variance explained by a model including all the predictor variables, except for the predictor in question

were associated with lower amounts of stress on workdays. Additionally, the results showed that both high PA and higher BMI were associated with a lower amount of recovery during sleep. Additional PA (above the generally recommended aerobic PA level of over 150 min of moderate PA per week), was associated with the additional health benefits of a low amount of HRV-based stress on workdays and during working hours. Lower BMI was associated with better recovery during sleep, expressed by a greater amount and magnitude of recovery reactions (i.e. quality of recovery). This suggests that PA in the long term resulting in improved physical fitness has a positive effect on recovery, even though high PA may disturb recovery during the following night. The results of the present study showing an association of BMI and objectively measured PA with HRV-based stress during the workday are in line with previous studies.

The finding of the present study on the association of high PA with low HRV-based stress on workdays is in line with previous studies. Both moderate and vigorous PA are found to be associated with higher HRV [29]. Additionally, PA has been found to have positive effects on subjective stress. For instance, Birdee et al. [42] found that, among a large group of employees, physically active employees reported less difficulty coping with stress, more happiness and a higher rate of competency than inactive employees. Our previous study used the same measurement method to assess stress as in the present study, and found higher PA and physical fitness were associated with lower stress among men [43]. However, to our knowledge, this study is unique in its focus on the additional health benefits from PA exceeding the recommended level, in the context of stress. The results showed that PA level affects stress percentage more than BMI, especially in women, and the decrease in the amount of stress following a change from inactivity to high PA appears to be impossible to achieve by weight loss alone. When stress percentage was calculated without the time spent on PA, the association between higher PA with lower stress percentage remained (data not shown).

The present findings of an association between lower BMI and lower amount of stress on workdays, and an association of higher BMI with lower amount of stress during working hours, are also in line with previous studies. Furthermore, an additional analysis (data not shown) showed that having a higher BMI was associated with a higher amount of PA during working hours. Previously, HRV profiles were found to be relatively poor among obese individuals [44] and improved after weight loss [45]. Previous studies also suggest that individuals with lower socioeconomic status are more likely to be obese and more likely to be in physically active employment than their counterparts with higher socioeconomic status [46, 47]. So, time spent in PA leads to less time for other physiological body states, such as stress, during working hours. Another possible explanation for these findings is that among obese individuals, the physiological state of the body is detected as PA instead of stress, as HR increases and HRV decreases easily. Therefore, caution is required when interpreting the results. Previously, the association of BMI with stress has been studied using mainly subjective methods. For instance, Nyberg et al. [16] found both obesity and being underweight to be associated with high levels of work-related stress [16], independent of sex. Additionally, employees of normal weight report the lowest prevalence of emotional exhaustion and chronic psychological complaints compared with underweight, overweight and obese individuals [17]. In general, the evidence is weak and inconsistent for associations of psychosocial factors at work with weight-related outcomes [22]. However, based on previous [43–45] and present results, the association of obesity with HRV and HRV-based stress seems to be consistent.

The group of high active, consisting largely of young and normal-weight individuals, had the best quality of recovery during sleep when age and weight were not taken into account. The linear models revealed that BMI and age explained greater proportion of variance in the quality of recovery than the level of PA. Further, the linear models showed that the non-significant association of high PA with lower quality of recovery during sleep was negative. Additionally, high PA was significantly associated with lower amount of recovery during sleep. This finding may be explained by the estimation of PA level occurring on the same days that stress and recovery during sleep were determined. We did not take into account the timing of PA in the analysis of the present study. The findings of Myllymäki et al. [48] suggest that vigorous late-night exercise may have effects on cardiac autonomic control of heart during the first sleeping hours. They found higher nocturnal HR after the exercise day compared to the control day but no differences between the days in nocturnal HRV. Additionally, previous literature suggests that PA during working hours and leisure-time may show different effects on cardiac autonomic regulation. High PA during working hours has been found to be associated with poor cardiovascular health, including reduced HRV [49]. Recovery of HRV is also dependent on training background, and type, intensity and duration of exercise [50]. The lower the physical fitness and the higher the intensity of exercise, the slower the recovery of HRV after exercise [51]. Hynynen et al. [52] reported that even an exercise that was perceived as light and easy may have prolonged effects on nocturnal HRV during the following night. Our previous study with a smaller study population used a subjective method to assess PA; using laboratory conditions to assess physical fitness, our previous results showed that physical fitness was associated with better recovery during sleep, even though PA was not [43]. In line with this Pietilä et al. [53] found good physical fitness to be associated with good recovery, even though PA was found to disturb the recovery of the following night. It appears that PA on the same day may disturb nighttime recovery, but in the long term, PA and good fitness enhance recovery during sleep. This is supported by our additional analysis (data not shown), which showed higher recovery in a day without PA compared with a day with PA, among high-PA individuals. Further, the present finding of an association of lower BMI with a higher amount and better quality of recovery supports the idea that good fitness enhances recovery during sleep. However, the effect of the timing of PA on HRV-based recovery during following night should be studied further.

The present findings suggest that, although older individuals are not stressed as often, their stress reactions are stronger and recovery is weaker than their younger counterparts. Weaker recovery among older individuals was expected, as it is known that aging reduces HRV [24]. Compared with PA and BMI, age was most strongly associated with the amount of stress during working hours, and intensity of stress and recovery reactions. These results suggest that recovery of older individuals is weakened. However, the findings of Soares-Miranda et al. [30] showing both cross-sectional and longitudinal association of PA with more favorable HRV among older adults emphasizes the importance of PA among older individuals. These findings should be considered for instance in policymaking when planning to lengthen working careers.

The results were similar between men and women. The variances explained by the linear models were mostly slightly higher for men. The men in this study had a slightly higher amount of stress than women during the whole workday and during working hours. Men also had a higher intensity of stress reactions and a lower amount and quality of recovery during sleep compared with women. This finding is in line with previous evidence that men have stronger physiological responses to psychological stress than women, including greater cardiovascular activation [18].

This study has strengths and weaknesses. While the measurement method may have had a significant impact on the measured PA levels, a strength of this study is that the weekly PA amount was calculated based on the objective measurement of PA periods lasting over 10 min. The validated ambulatory beat-to-beat R-R interval-based method [31, 54] used to assess the amount and intensity of PA has been shown to provide more accurate estimates of the intensity of PA than HR information [54, 55]. Even though the participants were informed to continue with normal daily living under the wellness assessment, individuals may have a tendency to be more active than usual during this type of short-time assessment. At least 5 consecutive days of pedometer monitoring has been suggested to achieve reliable and valid 1-year PA estimates [56]. However, another study suggests that three days would be sufficient to achieve valid results [57]. The existing literature indicates a need for valid, accurate and reliable measures of PA for assessing current and changing PA levels and the relationships between PA and health outcomes [58].

We used a novel HRV-based method to assess the amount and intensity of stress and recovery. HRV has been suggested as a feasible stress assessment method [59–61], and the stability of 24-h recording is high [24]. In our study, the sustainability of the HRV and HRV-based measures of stress and recovery between 2 consecutive days was quantified, and all the correlations were found to be statistically significant. The method used in the present study has been validated against neuroendocrine responses to stress, and the indicators of stress and recovery during sleep have been found to be associated with free salivary cortisol response after awakening [62]. Additionally, the method has been utilized in previous studies [43, 63–65] and the findings of these studies further support the validity and reliability of this HRV-based method. For instance, previous studies have found an association of higher HRV-based stress and lower recovery with higher perceived stress [63, 64]. Although traditional HRV measures are required to assess quality and clinical correlates of the recordings, these new ways of presenting findings improve the usability of HRV recordings in health promotion. Traditional HRV measures are not included in the main study analyses. However, the descriptive statistics show the similarity between the traditional HRV measures and the HRV-based stress and recovery variables. HRV-based methods that take individual characteristics and dynamic changes in cardiac autonomic activity into account and provide easily understandable variables of stress and recovery can be informative and suitable measures for field and clinical conditions. Individual written feedback together with verbal feedback and discussion of the HRV recording results would be optimal (an example of the feedback the participants received is shown in Additional file 4: Figure S1). It should be noted here that the method we used did not distinguish eustress from distress. However, division into these two types of stress may be impractical because of similar physiological responses to both stress forms.

The major strength of the present study is the very large sample, which included both non-manual and manual labor employees. The study sample was not a random sample from the Finnish population, but a real-life sample of Finnish employees who voluntary performed beat-to-beat R-R interval recording as a part of the preventive occupational health care programs provided by their employers. Even though the participants of the present study may represent a group of employees who are more interested about their health than the average person, their BMI profiles were similar to ordinary working-aged Finnish people [66], except for the individuals with BMI over 40 were excluded from the present study. Thus, the findings of this study are generalizable to ordinary Finnish employees. Nonetheless, it is a weakness of the present study that as it was a real-life/data-mining type study, we did not have detailed individual information about the participants, including the information about the profession or socioeconomic status of the participants. Additionally, the fact that the information about weight and height (needed for BMI calculation) was based on self-reports may have yielded an underestimation of BMI in the study sample [67]. Most of the participants were apparently healthy; however, the inclusion of individuals with chronic diseases and/or on medications may have had an effect on HRV. However, our large sample size should have compensated for these inclusions, leading to statistically significant results. The use of real-life data was a strength of the study; however, daytime stress is affected by many confounding factors [24], very few of which were controlled for in our analysis. Participants who had consumed alcohol on the monitoring days were excluded from the analyses of the present study. Unfortunately, we did not have information for example about participants' smoking or caffeine consumption. Clearly, outside factors appear to have affected HRV-based stress because the explanation ratios of the linear models were rather small. In summary, the large real-life study sample of the present study can be considered as either a strength or a weakness depending on the perspective. For instance, in future it would be interesting to study the association of socioeconomic status with HRV-based stress and recovery by taking into account the effect of the level of PA.

This study used novel, validated [43, 62–64] HRV-based technology to assess stress, recovery and PA in real-life. The results suggest that high PA and lower BMI are associated with a lower amount of stress on workdays independently of age and sex. Additionally, the results suggest that having a lower BMI is associated with lower intensity of stress reactions on workdays, and a higher amount and better quality of recovery during sleep. This, together with existing evidence, suggests that long-term PA, resulting in improved physical fitness, has a positive effect on recovery, even though high PA was associated with a lower amount of recovery on the following night. In summary, the present results support the beneficial effects of PA on health. However, owing to the cross-sectional study design, it is not possible to draw conclusions about the direction of the associations. Previous literature suggests that the association may be reciprocal; that is, inactivity may cause stress or stress may be a factor that leads to inactivity. Overall, most of the literature finds that the experience of stress impairs efforts to be physically active [68], even though PA is beneficial in stress management [65]. More research on the causal relations between PA and HRV-based stress and recovery is needed. Randomized controlled trials investigating the effect of increasing different types of PA and timing of PA are warranted.

Conclusions

The results provide important information about the associations of objectively measured PA and body weight with objectively measured physiological stress in Finnish employees. This information could be used in future policymaking and focused upon by employers. Although the beneficial effects of PA on health are well documented, these results may be beneficial by, for example, increasing employer willingness to invest greater resources in increasing the PA of employees.

Additional files

Additional file 1: Table S1. Detection of heart rate variability-based stress and recovery. (DOCX 21 kb)

Additional file 2: Table S2. Characteristics (mean ± SD) of the measures derived from beat-to-beat R-R interval recording, by physical activity groups. Table S3. Characteristics (mean ± SD) of the measures derived from beat-to-beat R-R interval recording, by body mass index groups. Table S4. Characteristics (mean ± SD) of the measures derived from beat-to-beat R-R interval recording, by age groups. (DOCX 31 kb)

Additional file 3: Table S5. The number of participants by age, physical activity and body mass index groups. (DOCX 21 kb)

Additional file 4: Figure S1. An example (1 of the 3 days) of the feedback from the wellbeing assessment of the participants. (PDF 262 kb)

Abbreviations

ANS, autonomic nervous system; BMI, body mass index; HF, high frequency; HR, heart rate; HRV, heart rate variability; LF, low frequency; MET, multiple of the resting metabolic rate; PA, physical activity; RMSSD, root mean square of successive R-R intervals; VO_2, oxygen uptake; VO_{2max}, maximal oxygen uptake

Acknowledgements

This study was supported by the Finnish Funding Agency for Technology and Innovation (Tekes) under Health Data Mining project, grant 40116/14. T. Föhr's work was supported by a personal grant from the Juho Vainio Foundation.

Availability of data and materials

Data is owned by Firstbeat Technologies Ltd. Researchers interested in using the data are advised to contact the corresponding author.

Authors' contributions
All authors participated in planning the study design and statistical analyses, they reviewed and edited the manuscript and approved the final manuscript. TF and JP drafted the manuscript. JP and EH carried out the analyses. TF is the guarantor of this work and accepts full responsibility for the content of the article.

Competing interests
T. Myllymäki is an employee of and H. Rusko is a stockholder in Firstbeat Technologies Ltd. They did not contribute to writing the study conclusions. No financial or other conflicts of interest are declared by the other authors.

Ethics approval and consent to participate
The data obtained from the R-R interval recordings were analyzed and anonymously stored in a database administered by the software manufacturer (Firstbeat Technologies Ltd). Firstbeat Technologies Ltd and each service provider (e.g., occupational health care unit) who conducted the recordings for employees (participants) signed an agreement providing Firstbeat Technologies Ltd the right to store the data in an anonymized form and to use it for development and research purposes with a statement that employers must inform their employees about its use. According to the agreement, Firstbeat Technologies Ltd extracted an anonymous data file from the registry for the present research purposes. The study protocol was approved by the ethics committee of Tampere University Hospital (Reference No R13160).

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Received: 19 April 2016 Accepted: 28 July 2016
Published online: 02 August 2016

References
1. Haskell WL, Blair SN, Hill JO. Physical activity: health outcomes and importance for public health policy. Prev Med. 2009;49(4):280–2.
2. Kujala UM. Evidence on the effects of exercise therapy in the treatment of chronic disease. Br J Sports Med. 2009;43(8):550–5.
3. Warburton DE, Nicol CW, Bredin SS. Health benefits of physical activity: the evidence. CMAJ. 2006;174(6):801–9.
4. Physical Activity Guidelines Advisory Committee. Report of the Physical Activity Guidelines Advisory Committee. 2008. http://health.gov/paguidelines/. Accessed 4 Dec 2015.
5. Fletcher GF, Ades PA, Kligfield P, Arena R, Balady GJ, Bittner VA, et al. Exercise standards for testing and training: a scientific statement from the American Heart Association. Circulation. 2013;128(8):873–934.
6. Jonsdottir IH, Rödjer L, Hadzibajramovic E, Börjesson M, Ahlborg G. A prospective study of leisure-time physical activity and mental health in Swedish health care workers and social insurance officers. Prev Med. 2010; 51(5):373–7.
7. Helldán A, Helakorpi S. Health Behaviour and Health among the Finnish Adult Population, Spring 2014. 2015. http://urn.fi/URN:ISBN:978-952-302-447-2. Accessed 4 Dec 2015.
8. Vartanian LR, Shaprow JG. Effects of weight stigma on exercise motivation and behavior: a preliminary investigation among college-aged females. J Health Psychol. 2008;13(1):131–8.
9. Shook RP, Blair SN, Duperly J, Hand GA, Matsudo SM, Slavin JL. What is causing the worldwide rise in body weight? US Endocrinol. 2014;10:44–52.
10. Kivimäki M, Nyberg ST, Batty GD, Fransson EI, Heikkilä K, Alfredsson L, et al. Job strain as a risk factor for coronary heart disease: a collaborative meta-analysis of individual participant data. The Lancet. 2012;380(9852):1491–7.
11. Kivimäki M, Virtanen M, Elovainio M, Kouvonen A, Väänänen A, Vahtera J. Work stress in the etiology of coronary heart disease—a meta-analysis. Scand J Work Environ Health. 2006;32(6):431–42.
12. Kouvonen A, Kivimäki M, Cox SJ, Cox T, Vahtera J. Relationship between work stress and body mass index among 45,810 female and male employees. Psychosom Med. 2005;67(4):577–83.
13. Sonnentag S, Jelden S. Job stressors and the pursuit of sport activities: a day-level perspective. J Occup Health Psychol. 2009;14(2):165–81.
14. Kouvonen A, Vahtera J, Oksanen T, Pentti J, Väänänen AK, Heponiemi T, et al. Chronic workplace stress and insufficient physical activity: a cohort study. Occup Environ Med. 2013;70(1):3–8.
15. Asztalos M, Huybrechts I, Temme E, Van Oyen H, Vandevijvere S. Association of physical activity, waist circumference and body mass index with subjective health among Belgian adults. Eur J Public Health. 2013;24(2):205–9.
16. Nyberg ST, Heikkilä K, Fransson EI, Alfredsson L, De Bacquer D, Bjorner JB, et al. Job strain in relation to body mass index: pooled analysis of 160 000 adults from 13 cohort studies. J Intern Med. 2012;272:65–73.
17. Proper KI, Koppes LLJ, van Zwieten MHJ, Bemelmans WJE. The prevalence of chronic psychological complaints and emotional exhaustion among overweight and obese workers. Int Arch Occup Environ Health. 2012;85(5): 537–45.
18. Wardle J, Chida Y, Gibson EL, Whitaker KL, Steptoe A. Stress and Adiposity: A Meta-Analysis of Longitudinal Studies. Obesity. 2011;19(4):771–8.
19. Block JP, He Y, Zaslavsky AM, Ding L, Ayanian JZ. Psychosocial stress and change in weight among US adults. Am J Epidemiol. 2009;170(2):181–92.
20. Overgaard D, Gyntelberg F, Heitmann B. Psychological workload and body weight: is there an association? A review of the literature. Occup Med. 2004; 54(1):35–41.
21. Armon G, Shirom A, Berliner S, Shapira I, Melamed S. A prospective study of the association between obesity and burnout among apparently healthy men and women. J Occup Health Psychol. 2008;13(1):43–57.
22. Solovieva S, Lallukka T, Virtanen M, Viikari-Juntura E. Psychosocial factors at work, long work hours, and obesity: a systematic review. Scand J Work Environ Health. 2013;39(3):241–58.
23. Montano N, Porta A, Cogliati C, Costantino G, Tobaldini E, Casali KR, et al. Heart rate variability explored in the frequency domain: a tool to investigate the link between heart and behavior. Neurosci Biobehav Rev. 2009;33(2):71–80.
24. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology: Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Eur Heart J. 1996;93(5):1043–65.
25. Malliani A, Pagani M, Lombardi F, Cerutti S. Cardiovascular neural regulation explored in the frequency domain. Circulation. 1991;84(2):482–92.
26. Acharya UR, Joseph KP, Kannathal N, Lim CM, Suri JS. Heart rate variability: a review. Med Biol Eng Comput. 2006;44(12):1031–51.
27. Jarczok MN, Kleber ME, Koenig J, Loerbroks A, Herr RM, Hoffmann K, et al. Investigating the associations of self-rated health: heart rate variability is more strongly associated than inflammatory and other frequently used biomarkers in a cross sectional occupational sample. PloS one. 2015;10(2): e0117196. doi:10.1371/journal.pone.0117196.
28. Chouchou F, Desseilles M. Heart rate variability: a tool to explore the sleeping brain? Front Neurosci. 2014;8:402. doi:10.3389/fnins.2014.00402.
29. Rennie KL, Hemingway H, Kumari M, Brunner E, Malik M, Marmot M. 2003. Effects of moderate and vigorous physical activity on heart rate variability in a British study of civil servants. Am J Epidemiol. 2003;158(2):135–43.
30. Soares-Miranda L, Sattelmair J, Chaves P, Duncan G, Siscovick DS, Stein PK, et al. Physical activity and heart rate variability in older adults: the Cardiovascular Health Study. Circulation. 2014;129(21):2100–10.
31. Mutikainen S, Helander E, Pietila J, Korhonen I, Kujala UM. Objectively measured physical activity in Finnish employees: a cross-sectional study. BMJ Open. 2014. doi:10.1136/bmjopen-2014-005927.
32. Saalasti S. Neural networks for heart rate time series analysis [dissertation]. Jyväskylä: University of Jyväskylä; 2003. https://jyx.jyu.fi/dspace/bitstream/handle/123456789/13267/951391707X.pdf?sequence=1. Accessed 9 Dec 2015.
33. Kettunen J, Saalasti S, inventors; Firstbeat Technologies Ltd, assignee. Procedure for deriving reliable information on respiratory activity from heart period measurement. United States patent US 7,460,901 B2. 2 Dec 2008. http://worldwide.espacenet.com/publicationDetails/originalDocument?CC=US&NR=7460901B2&KC=B2&FT=D&ND=4&date=20081202&DB=EPODOC&locale=fi_FI. Accessed 9 Dec 2015.
34. Kettunen J, Saalasti S, inventors; Firstbeat Technologies Ltd, assignee. Procedure for detection of stress by segmentation and analyzing heart beat signal. United States patent US 7,330,752 B2.12 Feb 2008. http://worldwide.espacenet.com/publicationDetails/originalDocument?FT=D&date=20080212&DB=EPODOC&locale=fi_FI&CC=US&NR=7330752B2&KC=B2&ND=4. Accessed 9 Dec 2015.

35. Martinmäki K, Rusko H, Kooistra L, Kettunen J, Saalasti S. Intraindividual validation of heart rate variability indexes to measure vagal effects on hearts. Am J Physiol Heart Circ Physiol. 2006;290(2):640–7.
36. Firstbeat Technologies Ltd. Stress and recovery analysis method based on 24-hour heart rate variability. 2014. http://www.firstbeat.com/app/uploads/2015/10/Stress-and-recovery_white-paper_20145.pdf. Accessed 8 Dec 2015.
37. Firstbeat Technologies Ltd. EPOC based training effect assessment. 2012. http://www.firstbeat.com/app/uploads/2015/10/white_paper_training_effect.pdf. Accessed 8 Dec 2015.
38. Ross RM, Jackson AS. Exercise concepts, calculations, and computer applications. Carmel: Benchmark Press; 1990.
39. Jones NL. Clinical exercise testing. 3rd ed. Philadelphia: W.B. Saunders; 1988.
40. Jackson AS, Blair SN, Mahar MT, Wier LT, Ross RM, Stuteville JE. Prediction of functional aerobic capacity without exercise testing. Med Sci Sports Exerc. 1990;22(6):863–70.
41. Osborne JW. Improving your data transformations: Applying the Box-Cox transformation. Practical Assessment, Research & Evaluation. 2010;15(12):1–9.
42. Birdee GS, Byrne DW, McGown PW, Rothman RL, Rolando LA, Holmes MC, et al. Relationship between physical inactivity and health characteristics among participants in an employee-wellness program. J Occup Environ Med. 2013;55(5):514–9.
43. Teisala T, Mutikainen S, Tolvanen A, Rottensteiner M, Leskinen T, Kaprio J, et al. Associations of physical activity, fitness, and body composition with heart rate variability-based indicators of stress and recovery on workdays: a cross-sectional study. J Occup Med Toxicol. 2014;34:26–40. doi:10.1186/1745-6673-9-16.
44. Zahorska-Markiewicz B, Kuagowska E, Kucio C, Klin M. Heart rate variability in obesity. Int J Obes Relat Metab Disord. 1993;17(1):21–3.
45. Rissanen P, Franssila-Kallunki A, Rissanen A. Cardiac parasympathetic activity is increased by weight loss in healthy obese women. Obes Res. 2001;9(10):637–43.
46. Lallukka T, Sarlio-Lähteenkorva S, Kaila-Kangas L, Pitkäniemi J, Luukkonen R, Leino-Arjas P. Working conditions and weight gain: a 28-year follow-up study of industrial employees. Eur J Epidemiol. 2008;23(4):303–10.
47. McLaren L. Socioeconomic status and obesity. Epidemiol Rev. 2007;29:29–48.
48. Myllymäki T, Kyröläinen H, Savolainen K, Hokka L, Jakonen R, Juuti T, et al. Effects of vigorous late-night exercise on sleep quality and cardiac autonomic activity. J Sleep Res. 2011;20:146–53.
49. Kang D, Kim Y, Kim J, Hwang Y, Cho B, Hong T, et al. Effects of high occupational physical activity, aging, and exercise on heart rate variability among male workers. Ann Occup Environ Med. 2015;27(1):1–11.
50. Kaikkonen P, Rusko H, Martinmäki K. Post-exercise heart rate variability of endurance athletes after different high-intensity exercise interventions. Scand J Med Sci Sports. 2008;18(4):511–9.
51. Seiler S, Haugen O, Kuffel E. Autonomic recovery after exercise in trained athletes: intensity and duration effects. Med Sci Sports Exerc. 2007;39(8):1366–73.
52. Hynynen E, Vesterinen V, Nummela A, Rusko H. Effects of moderate and heavy endurance exercise on nocturnal HRV. Int J Sports Med. 2010;31:428–32.
53. Pietilä J, Helander E, Myllymäki T, Korhonen I, Jimison H, Pavel M. Exploratory analysis of associations between individual lifestyles and heart rate variability -based recovery during sleep. 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society 2015. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7318862. Accessed 10 Jun 2016.
54. Smolander J, Ajoviita M, Juuti T, Nummela A, Rusko H. Estimating oxygen consumption from heart rate and heart rate variability without individual calibration. Clin Physiol Funct Imaging. 2011;31(4):266–71.
55. Firstbeat Technologies Ltd. VO2 estimation method based on heart rate measurement. 2005. http://www.firstbeat.com/userData/firstbeat/download/white_paper_vo2_estimation.pdf. Accessed 10 Jun 2016.
56. Kang M, Bassett DR, Barreira TV, Tudor-Locke C, Ainsworth B, Reis JP, et al. How many days are enough? A study of 365 days of pedometer monitoring. Res Q Exerc Sport. 2009;80(3):445–53.
57. Tudor-Locke C, Burkett L, Reis J, Ainsworth B, Macera C, Wilson D. How many days of pedometer monitoring predict weekly physical activity in adults? Prev Med. 2005;40(3):293–8.
58. Prince SA, Adamo KB, Hamel ME, Hardt J, Connor Gorber S, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. Int J Behav Nutr Phys Act. 2008. doi:10.1186/1479-5868-5-56.
59. Van Amelsvoort L, Schouten E, Maan A, Swenne C, Kok F. Occupational determinants of heart rate variability. Int Arch Occup Environ Health. 2000;73(4):255–62.
60. Sammito S, Thielmann B, Seibt R, Klussmann A, Weippert M, Böckelmann I. Guideline for the application of heart rate and heart rate variability in occupational medicine and occupational science. ASU Int. 2015. doi:10.17147/ASUI.2015-06-09-03.
61. Beauchaine TP, Thayer JF. Heart rate variability as a transdiagnostic biomarker of psychopathology. Int J Psychophysiol. 2015;98(2):338–50. doi:10.1016/j.ijpsycho.2015.08.004.
62. Rusko H, Rönkä T, Uusitalo A, Kinnunen U, Mauno S, Feldt T et al. Stress and relaxation during sleep and awake time, and their associations with free salivary cortisol after awakening. Nordic Ergonomics Society congress 2006. http://www.firstbeat.com/app/uploads/2015/10/rusko_et_al_nes_2006_congress.pdf. Accessed 9 Dec 2015.
63. Uusitalo A, Mets T, Martinmäki K, Mauno S, Kinnunen U, Rusko H. Heart rate variability related to effort at work. Appl Ergon. 2011;42(6):830–8.
64. Föhr T, Tolvanen A, Myllymaki T, Jarvela-Reijonen E, Rantala S, Korpela R, et al. Subjective stress, objective heart rate variability-based stress, and recovery on workdays among overweight and psychologically distressed individuals: a cross-sectional study. J Occup Med Toxicol. 2015;10:39. doi:10.1186/s12995-015-0081-6.
65. Föhr T, Tolvanen A, Myllymäki T, Järvela-Reijonen E, Peuhkuri K, Rantala S et al. Physical activity, heart rate variability-based stress and recovery, and subjective stress during a 9-month study period. Scand J Med Sci Sports. Advance online publication. doi: 10.1111/sms12683
66. Männistö S, Laatikainen T, Vartiainen E. Suomalaisten lihavuus ennen ja nyt. 2012. http://urn.fi/URN:ISBN:978-952-245-792-9. Accessed 29 Jun 2016.
67. Gorber SC, Tremblay M, Moher D, Gorber B. A comparison of direct vs. self-report measures for assessing height, weight and body mass index: a systematic review. Obesity Reviews. 2007;8(4):307–26.
68. Stults-Kolehmainen MA, Sinha R. The effects of stress on physical activity and exercise. Sports Med. 2014;44(1):81–121.