Karlsruher Institut für Technologie (KIT)

Fakultät für Geistes- und Sozialwissenschaften

Effects of Aerobic Exercise Training on Stress Reactivity in Every-Day Life

Dissertation zur Erlangung des akademischen Grades

eines DOKTORS DER PHILOSOPHIE

(Dr. phil.)

Von der Fakultät für Geistes- und Sozialwissenschaften

des

Karlsruher Instituts für Technologie (KIT)

angenommene

DISSERTATION

vorgelegt von:

M.A. **Birte von Haaren**

geboren in Balingen

Dekan: Prof. Dr. Andreas Böhn

1. Gutachter: Prof. Dr. Klaus Bös

2. Gutachter: Prof Dr. Ulrich Ebner-Priemer

Tag der mündlichen Prüfung: 01. Juli 2015

DOI: 10.5445/IR/1000049411

Acknowledgments

Die vorliegende Arbeit entstand im Rahmen meiner Tätigkeit als wissenschaftliche Mitarbeiterin der Young Investigator Group hiper.campus und des Instituts für Sport und Sportwissenschaft des Karlsruher Instituts für Technologie.

Zuallererst gilt mein aufrichtiger Dank meinem Doktorvater Prof. Dr. Klaus Bös, der mich über seine hervorragende wissenschaftliche Unterstützung hinaus gefördert und begleitet hat und mir die Promotion ermöglichte. Für die intensive und wissenschaftlich anspruchsvolle Unterstützung bei den Publikationen, der Methodik und zahlreichen anderen Aspekten möchte ich mich bei meinem Zweitgutachter, Prof. Dr. Ulrich Ebner-Priemer sehr herzlich bedanken.

Mein Dank gilt auch dem gesamten hiper.campus Team um Dr. Stefan Hey für die unvergessliche interdisziplinäre Zusammenarbeit und das Vertrauen in meine Arbeit. Bedanken möchte ich mich auch bei Dr. Sascha Härtel für den Input im Bereich der Ausdauerdiagnostik und die langjährige persönliche Unterstützung. Simone Löffler danke ich für die gewinnbringende und konstruktive Kritik und die schöne Zeit als langjährige enge Kollegin. Mein Dank gilt auch Jörg Ottenbacher, der im Bereich der technischen Umsetzung meines Vorhabens unglaublich Vieles möglich machte. Außerdem danke ich Panagiota Anastasopoulou, Hatem Sghir, Jürgen Stumpp, Rainer Neumann, Claudia Karger, Lars Schlenker, Marco Wildersinn und meiner lieben Kollegin Layal Shammas für die gemeinsame Arbeit und die schönen Momente.

Alwina Hermann, Claudia Albrecht und Judith Väth möchte ich für die wunderbare Freundschaft ganz besonders danken.

Meiner Schwester Anke und meiner besten Freundin Resi gilt mein tiefer Dank für ihr Verständnis und ihren riesigen Zuspruch und Rückhalt in den letzten Jahren.

Die bedingungslose und liebevolle Unterstützung durch meine Eltern haben mir diese Promotion erst ermöglicht, dafür bin ich unendlich dankbar.

Ich danke Dir lieber Andreas, dass Du mir durch Deine Liebe und Dein tiefes Vertrauen in meine Fähigkeiten geholfen hast, meinen Weg zu finden.

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Summary

In modern society we face multiple day-to-day challenges such as being in traffic, meeting deadlines, and organizing child care, all of which cause considerable stress. Prolonged stress exposure is associated with cardiovascular disease (Dimsdale, 2008), depression, anxiety, back pain, poor immune system, obesity and metabolic syndrome (Chrousos, 2009; Tamashiro, Sakai, Shively, Karatsoreos, & Reagan, 2011). Due to the health-enhancing effects of regular exercise on blood pressure, hemodynamic activity, neuroendocrine, inflammatory and hemostatic responses, it is suggested that regular exercise buffers the deleterious effects of psychological stressors by reduced physiological and emotional stress reactivity (Hamer, 2012). However, previous studies only partly support the assumption that regular exercise can reduce physiological and emotional stress reactivity (Crews & Landers, 1987; Forcier et al., 2006; Jackson & Dishman, 2006). Most of these previous studies used between-subject designs and artificial stressors, and did not consider the habitual physical activity level of participants. The few studies that used real-life stressors demonstrated encouraging results, but were all cross-sectional. No study investigated the effects of regular exercise on both, emotional and physiological stress reactivity using a real-life stressor and a randomized, controlled trial. Thus, the current thesis investigated the effects of a 20-week aerobic exercise training (AET) on physiological and emotional responses to real-life stress using a randomized, controlled trial and an inactive sample. To assess participants' physiological and psychological responses during every-day life, ambulatory assessment was used.

Sixty-one inactive male students were randomized to either AET or a control group. Participants of the AET group completed a supervised individually tailored 20-week AET to improve aerobic capacity (VO_2max). An effective AET intervention (significantly enhanced VO_2max) was presumed for the hypothesized effects of the intervention on real-life stress. Thus, as a manipulation check to assess aerobic capacity, VO_2max was determined via cardiopulmonary exercise testing pre- and post-intervention. To examine physiological and emotional reactivity to real-life stress, two specific real-life assessment periods were chosen. The pre-intervention assessment was set to the beginning of the semester and the post-intervention assessment was set to a real-life stressful episode (academic examinations). During both periods participants completed two days of measurement. We assessed physiological responses continuously using an ambulatory ECG monitor with an integrated accelerometer to assess physical activity. In addition, participants completed electronic diary entries of perceived stress, mood and context information repeatedly every two hours.

Chapter 1 gives a general introduction on the scope of the present thesis, outlines the structure of the thesis and displays how the different chapters contribute to the whole concept of the thesis. Furthermore, the chapter provides the theoretical background and closes with the study design.

Chapter 2 The activity-affect association in inactive people

Insights into the association between physical activity/exercise and affect are important for the analysis of the effects of regular exercise on emotional stress responses. Previous studies included active and inactive people, but they do not necessarily exhibit the same affective reactions to physical activity and exercise. Thus, in *Chapter 2* we analyzed whether the *feel-better effect* of unstructured physical activity observed in previous studies can be confirmed during every-day life in sedentary people. Using the baseline data (no intervention) of the first year of data collection (N = 30), we assessed the association between unstructured physical activity and subjective ratings of the three basic mood dimensions, energetic arousal, valence and calmness. Therefore the mean activity intensity was calculated over the last 15 min and related to the subsequent diary prompt. Within-subject correlations revealed non-significant associations between physical activity and affect. Due to the high variability in within-subject correlations, we conclude that not all inactive people show the same affective reactions to physical activity in every-day life. Thus, the general assumption of a *feel better effect* of physical activity might not be suitable for this target group.

Chapter 3 Regular exercise and emotional stress reactivity

Chapter 3 reports on the effects of the randomized, controlled trial on emotional responses to real-life stress in 61 male inactive students. We investigated whether a preventive 20-week AET can reduce emotional reactivity to real-life stress. Therefore we analyzed whether the interaction between the factor "group" (AET versus control group) and the factor "perceived stress" (subjective diary ratings) predicted the level of negative affect. Using multilevel models we calculated emotional stress reactivity separately for baseline (pre-intervention) and stressful episode (academic examinations). The results of the cardiopulmonary exercise tests revealed a significant VO_2max improvement in the AET group compared to the control group, $F(1, 56) = 55.3$; $p < .001$; $\eta 2 = .51$. Furthermore, after participating in the 20-week AET, the experimental group exhibited lower emotional stress reactivity compared with their control counterparts ($\beta = -0.18$, $t = -3.55$, $p < .001$) during the real-life stressful episode. Thus, AET appears to be a promising strategy against the negative health effects of accumulated negative affect.

Chapter 4 Regular exercise and physiological stress reactivity

Chapter 4 reports on the effects of the randomized, controlled trial on physiological stress responses during real-life stress. We hypothesized that a 20-week AET does reduce physiological stress reactivity to real-life stress in sedentary students. Therefore we analyzed heart rate variability (LF/HF, RMSSD) based on the two days of ambulatory ECG recordings during baseline and stressful episode, and controlled for physical activity and perceived stress. Multilevel analyses revealed that the AET group showed significantly decreased LF/HF ($p = .011$) and increased RMSSD ($p = .021$) to real-life stress compared to the control group. Using a longitudinal design and a real-life stressor, we could demonstrate that exercise appears to buffer the deleterious effects of stress on the autonomic nervous system.

Chapter 5 closes with the general conclusions: In summary, the present thesis provides empirical support that regular exercise can lead to improved emotional and physiological responses during real-life stress. Thus, regular exercise appears to be a promising strategy against the negative health effects of accumulated emotional and physiological stress reactivity in every-day life of sedentary people.

Zusammenfassung

Die moderne Gesellschaft setzt uns täglich vielerlei Herausforderungen wie zum Beispiel im Stau stehen, Deadlines einhalten oder die Kinderbetreuung organisieren aus, die zu erheblichem Stress führen. Anhaltende Stressbelastung kann zu kardiovaskulären Erkrankungen (Dimsdale, 2008), Depressionen, Angstzuständen, Rückenschmerzen, schwachem Immunsystem, Übergewicht und metabolischem Syndrom führen (Chrousos, 2009; Tamashiro et al., 2011). Sportliche Aktivität beeinflusst den Blutdruck sowie hämodynamische und hämostatische, neuroendokrine und Entzündungsprozesse gesundheitsförderlich. Daher wird angenommen, dass sportliche Aktivität die schädlichen Wirkungen von Stress auf diese Bereiche abzupuffern vermag (Hamer, 2012). Bisherige Studien belegen allerdings nur teilweise die Annahme, dass sportliche Aktivität die physiologische und emotionale Stressreaktivität reduziert (Crews & Landers, 1987; Forcier et al., 2006; Jackson & Dishman, 2006). Die bisherigen Studien basieren hauptsächlich auf querschnittlichen Designs und im Labor künstlich erzeugtem Stress, das habituelle Aktivitätsverhalten der Studienteilnehmer wurde aber nicht berücksichtigt. Bisher wurde der Zusammenhang zwischen sportlicher Aktivität und Stressreaktivität im Alltag nur von wenigen Querschnittsstudien untersucht. Dagegen wurde der Effekt sportlicher Aktivität bisher in keiner Studie sowohl auf die emotionale als auch die physiologische Stressreaktivität mithilfe einer randomisierten kontrollierten Längsschnittstudie und einem realitätsnahen Stressor untersucht. Daher untersuchte die vorliegende Dissertation anhand eines randomisierten kontrollierten Designs die Auswirkungen eines 20-wöchigen Ausdauertrainings auf die physiologische und emotionale Stressreaktivität im Alltag bei Inaktiven. Um die emotionale und physiologische Stressreaktivität im Alltag zu erfassen, wurde ambulantes Assessment eingesetzt.

61 inaktive männliche Studierende wurden randomisiert entweder der Kontrollgruppe oder einer Gruppe mit einem aeroben Ausdauertraining zugeteilt. Die Teilnehmer der Ausdauergruppe absolvierten ein überwachtes individuell zugeschnittenes 20-wöchiges aerobes Ausdauertraining zur Verbesserung der aeroben Ausdauerleistungsfähigkeit (VO_2max). Um Effekte des Ausdauertrainings

auf die emotionale und physiologische Stressreaktivität nachweisen zu können, wurde eine signifikante Verbesserung der Ausdauerleistungsfähigkeit (signifikante Verbesserung der VO_2max) vorausgesetzt. Daher wurde die Effektivität des Ausdauertrainings anhand eines kardiopulmonalen Ausbelastungstests vor und nach der Intervention ermittelt. Um die physiologische und emotionale Stressreaktivität im Alltag zu erfassen, wurden zwei spezielle Erfassungszeiträume im Alltag ausgewählt. Die Baseline-Erfassung vor der Intervention wurde auf den Beginn des Semesters gelegt, für die Erfassung einer alltagsnahen stressreichen Phase nach der Intervention wurde die Prüfungsphase ausgewählt. Während beider Erfassungszeiträume wurden die Teilnehmer über zwei Tage hinweg untersucht. Die physiologische Stressreaktivität erhoben wir kontinuierlich mithilfe eines ambulanten EKG Gerätes mit integriertem Beschleunigungssensor zur Erfassung der körperlichen Aktivität. Zusätzlich machten die Teilnehmer alle zwei Stunden mithilfe von elektronischen Tagebüchern Angaben zu subjektivem Stressempfinden, Stimmung und Kontextinformationen.

Kapitel 1 gibt eine generelle Einführung in die Thematik der Dissertation und zeigt die Struktur sowie den Beitrag der einzelnen Kapitel zum Gesamtkonzept der Dissertation auf. Das Kapitel schließt mit der Beschreibung des Studiendesigns.

Kapitel 2 Der Zusammenhang zwischen Aktivität und Stimmung bei Inaktiven

Um die Auswirkungen regelmäßiger sportlicher Aktivität auf die emotionale Stressreaktivität analysieren zu können, ist ein Einblick in den Zusammenhang zwischen körperlicher/sportlicher Aktivität und Stimmung wichtig. Bisherige Studien beinhalteten sowohl inaktive als auch aktive Teilnehmer, die jedoch nicht automatisch dieselben affektiven Reaktionen hinsichtlich körperlicher Aktivität zeigen. Daher wird in *Kapitel 2* untersucht, ob der generell postulierte *feel better* Effekt körperlicher Alltagsaktivität sich auch bei Inaktiven zeigt. Anhand der Baseline Datenerhebung (keine Intervention) des ersten Untersuchungsjahres ($N = 30$) wurde der Zusammenhang zwischen der objektiv erfassten Alltagsaktivität und den Angaben bezüglich der drei Stimmungsdimensionen Wachheit, Valenz und Ruhe untersucht. Dazu wurde die durchschnittliche Aktivitätsintensität innerhalb der letzten 15 Minuten mit der darauffolgenden Stimmungsabfrage korreliert. Die Innersubjektkorrelationen zeigten keine signifikanten Zusammenhänge zwischen den drei Stimmungsdimensionen und körperlicher Alltagsaktivität. Aus der hohen intra- und interindividuellen Variabilität der Korrelationen schließen wir zum einen, dass Alltagsaktivität bei Inaktiven nicht immer zu Stimmungsveränderung führt und zum anderen, dass sich der Zusammenhang zwischen Aktivität und Stimmung zwischen Inaktiven unterscheidet. Daher scheinen die generellen Annahmen bezüglich eines *feel better* Effekts körperlicher Aktivität für diese Zielgruppe nicht zutreffend zu sein.

Kapitel 3 Regelmäßige Sportaktivität und emotionale Stressreaktivität

Kapitel 3 beschreibt die Auswirkungen der randomisierten kontrollierten Studie auf die emotionale Stressreaktivität von 61 inaktiven Studierenden. Wir untersuchten, ob ein präventives 20-wöchiges Ausdauertraining die emotionale Stressreaktivität bei Alltagsstress verbessern kann. Deshalb untersuchten wir, ob die Wechselwirkung zwischen dem Faktor „Gruppe“ (Ausdauertrainingsgruppe versus Kontrollgruppe) und dem Faktor „subjektiver Stress“ (aus den Angaben der elektronischen Tagebücher) das Ausmaß an negativer Stimmung im Alltag vorhersagt. Mithilfe von Mehrebenenanalysen (Zusammenhänge innerhalb und zwischen Personen) berechneten wir die emotionale Stressreaktivität jeweils separat für die Ausgangsuntersuchung und für die Prüfungsphase. Die Ergebnisse des Ausbelastungstests zeigten eine signifikante Verbesserung der Ausdauerleistungsfähigkeit der Ausdauergruppe im Vergleich zur Kontrollgruppe $F(1, 56) = 55.3$; $p < .001$; $\eta 2 = .51$. Die Ergebnisse der Mehrebenenanalysen zeigten eine reduzierte emotionale Stressreaktivität der Ausdauergruppe im Vergleich zur Kontrollgruppe ($\beta = -0.18$, $t = -3.55$, $p < .001$) während der Prüfungszeit, wohingegen dieser Effekt in der Ausgangsphase vor der Intervention nicht vorlag. Regelmäßiges Ausdauertraining scheint daher eine vielversprechende Strategie gegen negative Auswirkungen wiederholter emotionaler Stressreaktivität zu sein.

Kapitel 4 Regelmäßige Sportaktivität und physiologische Stressreaktivität

Kapitel 4 beschreibt die Auswirkungen der randomisierten kontrollierten Studie auf die physiologische Stressreaktivität im Alltag. Es wurde angenommen, dass ein 20-wöchiges aerobes Ausdauertraining die physiologische Stressreaktivität gegenüber Alltagsstress bei inaktiven Studierenden reduziert. Dazu wurden die Daten der zweitägigen ambulanten EKG-Messungen hinsichtlich der Herzratenvariabilität (LF/HF, RMSSD) ausgewertet und dabei die Alltagsaktivität und das subjektive Stressempfinden berücksichtigt. Die Ergebnisse der Mehrebenenanalysen zeigten eine signifikant reduzierte LF/HF Differenz (p = .011) und einen signifikant erhöhten RMSSD (p = .021) der Ausdauertrainingsgruppe im Vergleich zur Kontrollgruppe während der Prüfungsphase. Folglich konnten wir mithilfe eines alltagsnahen Stressors und der randomisierten kontrollierten Längsschnittstudie zeigen, dass ein regelmäßiges Ausdauertraining die schädlichen Auswirkungen von Prüfungsstress auf das autonome Nervensystem abzupuffern vermag.

Kapitel 5 schließt mit einem generellen Fazit: Zusammenfassend liefert die vorliegende Dissertation einen empirischen Nachweis dafür, dass regelmäßige Sportaktivität zu eine reduzierten emotionalen und physiologischen Stressreaktivität bei Alltagsstress führen kann. Daher zeigt sich regelmäßige Sportaktivität für den Alltag von Inaktiven als vielversprechende Strategie gegen die negativen gesundheitlichen Auswirkungen akkumulierter emotionaler und physiologischer Stressreaktivität.

1 General Introduction

In modern society we face multiple challenges, such as being stuck in traffic, meeting deadlines, organizing child care every day. While the body's natural alarm system – the *fight or flight* response – was necessary to save the lives of our ancestors, a chronic activation can have serious consequences for health. Our lifestyles and environment seem to be particularly permissive for stress-related disorders (Chrousos, 2009).

Cardiovascular disease is one of the leading causes of mortality and there is overwhelming evidence that stress is linked to cardiovascular disease (Dimsdale, 2008; Hamer, Taylor, & Steptoe, 2006; Hamer, 2012; Yusuf et al., 2004). In addition, prolonged stress-exposure has been associated with further mental and physical health outcomes like depression, anxiety, back pain, poor immune system, obesity and metabolic syndrome (Chrousos, 2009; Tamashiro et al., 2011). The detrimental effects of stress not only cause negative health outcomes for every individual but also produce immense costs for the economy, due to, for example, absenteeism at work, losses of productivity and health care treatment. Nichols et al., (2012) reported that the costs for cardiovascular disease were €196 billion a year for the overall European Union economy.

A lack of regular physical activity is among the most important risk factors identified for the development of heart disease (Yusuf et al., 2004). Furthermore, increasing evidence suggests a high association between stress and sedentariness (Hamer, 2012). To date it is well-known that exercise and improved physical fitness play an important role in reducing the risk for morbidity and mortality (Blair & Morris, 2009; Dimsdale, 2008; Joyner & Green, 2009; Warburton, Nicol, & Bredin, 2006; Yusuf et al., 2004). Due to the health-enhancing effects of regular exercise on blood pressure, hemodynamic activity, neuroendocrine, inflammatory and hemostatic responses, researchers have suggested that exercise buffers the deleterious effects of daily mental stressors. Since physiological and emotional stress responses have been identified as indicators for disease development (Collip et al., 2013; Lovallo, 2011), it is interesting to know whether regular exercise has the potential to influence these responses in a positive manner.

1.1 Aims

The current thesis aims to examine the effects of regular exercise on physiological and emotional responses to a real-life stressor (an academic examination). Using a randomized, controlled trial design and a sedentary population sample, the thesis investigates the effects of 20 weeks of aerobic exercise training (AET) on physiological and emotional reactivity to real-life stress.

1.2 Outline of the thesis

The present thesis encompasses five major chapters. In the following sections of the general introduction (*Chapter 1*), the origins of stress research and several stress concepts are presented then health aspects of stress relevant to the context of this thesis are highlighted. The subsequent sections describe physiological and affect-specific effects of regular exercise. The following sections contain a summary of existing research on the effects of regular exercise on emotional and physiological stress reactivity, tease out the shortcomings of previous research and highlight the meaningfulness of the present thesis. The general introduction closes with a summary of the study design, which is described explicitly with regard to the research question of every of the three peer-reviewed articles. The three chapters (*Chapter 2*, *Chapter 3*, *and Chapter 4*) report on the three peer-reviewed articles, which were published in international journals and are titled as follows in the present thesis:

- ***Chapter 2*: The activity-affect association in inactive people**
  (von Haaren et al., 2013)

- ***Chapter 3*: Regular exercise and emotional stress reactivity**
  (von Haaren, Haertel, Stumpp, Hey, & Ebner-Priemer, in press)

- ***Chapter 4*; Regular exercise and physiological stress reactivity**
  (von Haaren, Ottenbacher, Muenz, Neumann, Boes, & Ebner-Priemer, 2015)

Since the habitual physical activity level appears to have an impact on emotional and physiological stress responses to exercise, a sedentary population sample was chosen for the current thesis. Furthermore, affective changes in response to physical activity may influence the effects of exercise on emotional stress responses. Thus, in the first inquiry of the thesis, C*hapter 2* examines whether the postulated *feel-better effect* of physical activity and exercise from previous studies can be confirmed in sedentary students. Using the baseline sample of the randomized, controlled trial of study period 1 (*N* = 30), C*hapter 2* reports whether unstructured physical activity is associated with the three mood dimensions, valence, energetic arousal and calmness, in sedentary students.

Chapter 3 describes the analysis of the effects of the randomized, controlled trial (60 sedentary students) on emotional stress reactivity during real life. We presumed that 20 weeks of aerobic exercise training leads to improved aerobic capacity. Thus, at first we present the results of the aerobic exercise training that proved to be effective in increasing aerobic capacity of the intervention group. Furthermore, we examined whether 20 weeks of aerobic exercise training leads to decreased emotional stress reactivity during a real-life stressful episode (academic examinations).

Chapter 4 reports on the findings of 20 weeks of aerobic exercise training on physiological stress reactivity during real-life. Specifically, we investigated whether 20 weeks of aerobic exercise training leads to increased heart rate variability (HRV) during a real-life stressful episode. We conducted separate day- and night-specific analyses for the effects of the aerobic exercise training on HRV during academic examinations. *Chapter* 5 encompasses the general discussion on the main findings, methodological issues, implications for future research and closes with some general conclusions.

1.3 Theoretical background

1.3.1 Concepts of stress

Stress research has developed over approximately the last 100 years and thus different perspectives (psychological, environmental, and biological) and disciplines have advanced and distinctly developed the stress concept. Back in the 19th century, Claude Bernard recognized that the maintenance of life was dependent on the capacity of living organisms to keep the internal environment constant in a changing external environment (Lovallo, 2005). Walter Cannon coined the popular term, *fight or flight* syndrome. He also introduced the concept of *homeostasis* that advanced the understanding of physiological regulation to maintain internal stability against environmental change (Cannon, 1932) by improving the knowledge of the autonomic nervous system and the regulation of the body. He investigated the sensory nerves communicating the body´s state to the brain and the brain areas responsible for the ignition of compensatory responses (Cannon, 1932). Although Walter Cannon was the first to use the term *stress*, Hans Selye (1936) spread the concept of stress to the medical community. Due to Selye′s (1946) general adaptation syndrome it was quite early assumed, that immediate responses of the hypothalamic pituitary adrenal (HPA) axis and the sympathetic adrenal medulla (SAM) were important protective functions to prepare for the acute *fight or flight* situation, but indicated negative health consequences if prolonged activation through chronic exposure to stressors was present. The introduction of the concept of *allostatic load* by McEwen and Stellar (1993, p. 2094) with the idea of “the price the body pays over long periods of time for adapting to challenges” paved the way for the focus of research on health effects of continuing demands, which is known today as “chronic stress” (Lovallo, 2005).

While the biological perspective described above has contributed especially to our understanding of physiological mechanisms underlying stress, the environmental perspective has emphasized the effects of different stressors, from acute effects of major life-events to cumulative effects of several stressors at the same time and chronic stress, namely minor daily hassles (Bolger, DeLongis, Kessler, & Schilling, 1989; Stone, Ree, & Neale, 1987). In contrast to the original focus on how stress effects disease development (A. Meyer, 1951), nowadays there is increasing interest in beneficial adaptations to demands and researchers question why some people stay healthy and others do not (S. Cohen, Kessler, & Gordon, 1997). The psychological perspective contributes to the understanding of these differences between individuals because it emphasizes that stress responses are influenced by the individual´s appraisal of stressors. The interpretation of the meaning of an event and the evaluation of resources to adequately cope with the event together form the perception (S.

Cohen et al., 1997; Lazarus & Folkman, 1984). Another important role in the stress process is inhibited by emotions. The study of the interaction of stress and emotions has increased with the possibilities to assess them on a day-to-day basis over several weeks with daily diaries (Bolger et al., 1989) that account for their dynamic character. During stressful events, the association of positive affect and negative affect[1] is more inversely correlated than during non-stressful events, which is assumed to be due to a narrowed affective space during stress. Under stress, an individual tends to experience more negative affect and less positive affect (Zautra, Affleck, Tennen, Reich, & Davis, 2005).

What can we learn from the development of these different perspectives on stress? In recent years, authors have answered this question by integrating important aspects and advancing them. As a consequence, current definitions of stress include many key elements to improve our knowledge in the area of stress research (Contrada, 2011). For example, Ice and James (2006; see Figure 1) provide a process-oriented model of stress which integrates several perspectives on stress and defines it as:

> "…a process by which a stimulus elicits an emotional, behavioral, and/or physiological response, which is conditioned by an individual´s personal, biological and cultural context"
>
> (Ice & James, 2006, p. 6)

[1] Self-reported subjective feelings. Based on two factor models, positive and negative affect are the two main dimensions of mood (Watson, Clark, & Tellegen, 1988)

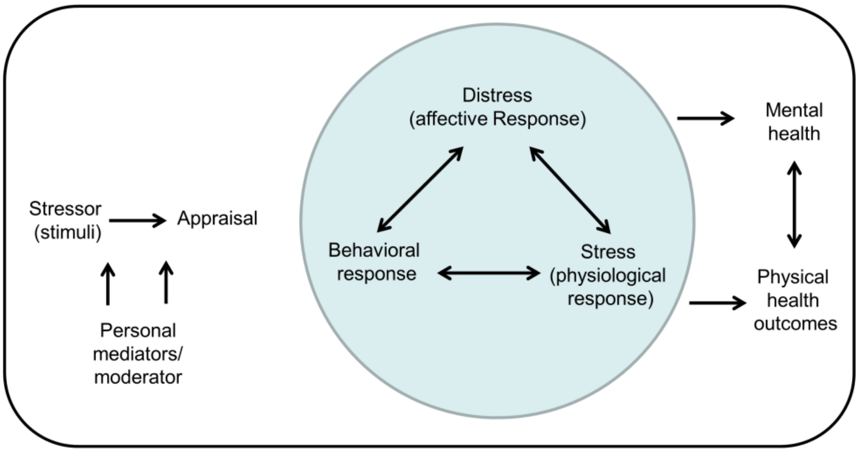

Figure 1.1: The stress process (Ice & James, 2006)

The model encompasses the whole stress process with stressors, personal mediators and moderators, including the three parts of stress responses (physiological, emotional, and behavioral) and the mental and physical health outcomes. Stressors are stimuli that initiate the stress process. Moreover they can be categorized as acute or chronic and as psychosocial, physical, or environmental. Several points, such as appraisal, personality, coping, social networks, and self-concept have been labeled as mediators or moderators and can be influenced by health status, as displayed at the end of the stress process or by behavioral response. For example, people with mental health problems may reduce social networks and thus become more vulnerable to stressors. Appraisal is an important aspect because it reflects the balance between demands and resources. For example, individuals of different social background will experience events differently, which illustrates that appraisal is influenced by personal mediators and cultural and biological context. Behavioral, emotional and physiological responses to stressors may appear individually or all at once. A positive behavioral response, such as utilizing social networks, can influence the physiological and emotional stress response (Ice & James, 2006).

Emotional responses are typically assessed by rating perceived anxiety, mood, or stress intensity and represent the individual´s level of distress. Physiological responses are basically reflected by the two stress axes, the hypothalamic-pituitary-adrenocortical axis (HPA) and the locus-ceruleus-sympathetic-adrenomedullary (LCSA) system. Finally, the context has an important impact on the stress process. The biological context refers to the biological state of an individual, for example, the age of an individual will have a large impact on exposure or appraisal to a stressor. High altitude is one example of the physical environment that induces individual adaptations. Different cultures may appraise, behave, or physiologically react differently to stressors; thus, the cultural context plays an important role in the stress process (Ice & James, 2006).

For the present thesis, the stress model of Ice and James (2006) was used because it integrates the environmental, psychological, and biological perspectives on stress and considers not only physiological but also emotional responses to stress. Furthermore, it illustrates that there is interplay between the parts of the stress process. For example, stress responses impact mental and physiological health, which influence an individual´s personal, biological and cultural context. In addition, negative health outcomes influence exposure to stressors, that is, poor health likely makes individuals more vulnerable to stress (Ice & James, 2006). Although it is suggested that exercise may affect different aspects of the stress-process (de Geus & Stubbe, 2007), the current thesis focuses on the effects of exercise on physiological and emotional responses to real-life stress.

The integration of interdisciplinary approaches in stress research has delivered important insights about social and psychological variables that act as risk or protective factors in the development of physical diseases. Moreover, central nervous, endocrine, and autonomic changes were identified as important factors of the stress response and their interaction with psychological, immunological, and cardiovascular processes could be linked. Additionally, behavioral responses have been studied and linked to physical health outcomes, while intervention strategies have been developed to reduce stress and improve health (Contrada, 2011). The following section reports on the relation between stress and cardiovascular health.

1.3.2 Stress and cardiovascular health

Numerous negative health consequences, for example, to the immune system, the endocrine system and the autonomic nervous system are associated with stress. This section only describes associations between stress and cardiovascular health, which are related to the autonomic nervous system, because they provide a relevant background for the current thesis. Exaggerated cardiovascular reactivity has been assumed to be the main cause for cardiovascular disease and acute events for a long time (Carroll, Lovallo, & Phillips, 2009; Clays et al., 2011; Dimsdale, 2008; Krantz & Manuck, 1984; Phillips, 2011). However, obesity and depression have been associated with blunted, rather than exaggerated cardiovascular reactivity (Carroll et al., 2009; Phillips, 2011). Lovallo (2011) recently suggested that both exaggerated and diminished cardiovascular stress reactivity are candidates for predicting adverse health outcomes.

In addition to the importance of physiological reactivity, psychological research has identified that emotional stress reactivity importantly contributes to our understanding of the stress-illness association. Negative affect is suggested to mediate the effect of stress on stress-related diseases which means that stress induces negative affect, which is accompanied by high arousal. Research conducted in a real-life setting found that the heart rate response is longer after negative compared to positive emotions (Brosschot & Thayer, 2003). Furthermore, accumulated enhanced negative affect has been associated with a higher risk for psychosis (Myin-Germeys, van Os, Schwartz, Stone, & Delespaul, 2001) and increased cardiac activation (Carels, Blumenthal, & Sherwood, 2000).

In sum, research shows that chronic stress induces physiological and psychological alterations that can result in negative health outcomes. Several important physiological stress-induced alterations are observed in the autonomic nervous system. Heart rate (HR) and heart rate variability (HRV) adequately reflect the balance of the autonomic nervous system during real life (Clays et al., 2011; Vrijkotte, van Doornen, & de Geus, 2000). The growing body of evidence linking stress to the most prevalent diseases and the highest economic costs insinuates that there is a need for preventive strategies to reduce stress-induced negative health outcomes (Dimsdale, 2008; Nichols et al., 2012). Exercise participation is suggested as one important preventive strategy to buffer deleterious cardiovascular and mental health outcomes. The following section reports on important physiological adaptations to exercise in the autonomic nervous system.

1.3.3 Physiological and emotional responses to exercise

Aerobic exercise training and autonomic nervous system

Exercise plays an important role in the prevention of various risk factors and diseases such as hypertension, diabetes and especially cardiovascular disease (Blair & Morris, 2009; Hamer, 2012; Warburton et al., 2006). The autonomic nervous system regulation of the heart is one of the various biological mechanisms suggested for the cardio protective effect of regular exercise (Sloan et al., 2009). The autonomic nervous system is predominantly responsible for the regulation of bodily functions.

Cardiovascular control areas and higher brain centers control the cardiovascular system and circulation, mainly through the activity of parasympathetic and sympathetic nerves (Aubert, Seps, & Beckers, 2003). In addition to the control of heart rate, the two nerve pathways supply important reflexogenic areas in the heart, which, when mechanically or chemically stimulated, induce reflexes that influence the heart and constrict blood vessels. Baroreceptor reflex activity is closely linked to these neural pathways and blood pressure plays a key role in increasing or decreasing activity of the two pathways (Aubert et al., 2003).

General cardiovascular changes that occur due to exercise entail important adaptations of the autonomic nervous system. Endurance exercise training induces increased blood volume load in the heart. Long-term athletic training increases the left ventricular diastolic cavity dimensions, wall thickness, and mass. Due to an increase in end-diastolic volume and a small increase in left ventricular mass, stroke volume increases and thus improves the heart′s ability to pump blood (Aubert et al., 2003). An increased stroke volume during either rest or submaximal and maximal exercise, results from increased heart volume and contractility as well as lower heart rate (longer diastole, per the Frank Starling mechanism). In addition, the increase of stroke volume and the decrease of heart rate lead to reduced metabolic load during rest and submaximal exercise intensity. Endurance training reduces systolic, diastolic, and mean arterial blood pressure during rest and submaximal conditions. Furthermore less catecholamine responses during submaximal exercise can be observed (Aubert et al., 2003). During exercise of low intensities, withdrawal of parasympathetic activity is predominantly responsible for reduced heart rate (Carter, Banister, & Blaber, 2003). If exercise intensity exceeds maximum oxygen consumption (VO_2max) of 50-60% an initial increase of sympathetic nerve activity and a significant decrease of parasympathetic activity is observed (Carter et al., 2003).

In contrast to acute exercise, regular endurance training leads to altered autonomic balance toward parasympathetic predominance due to increased vagal modulation of the heart rate and possibly reduced sympathetic activity during rest and submaximal exercise (Carter et al., 2003; Hautala, Kiviniemi, & Tulppo, 2009). Under a given submaximal exercise intensity, lower heart rate due to reduced sympathetic activity can be observed (Carter et al., 2003). Human studies using a cardiac autonomic blockade show reduced sympathetic control of heart rate after aerobic exercise training. Carter et al. (2003) has suggested exactly which peripheral adaptation mechanisms lead to exercise bradycardia: reduced baroreflex sensitivity and attenuated reflex heart rate response to myocardial stretch. In sum, regular endurance training appears to improve autonomic control through reduced sympathetic and increased parasympathetic activity.

Aerobic exercise is characterized by a steady state of oxygen demand and oxygen intake, and aims to increase aerobic capacity, for example VO_2max (Baquet, van Praagh, & Berthoin, 2003). Regular aerobic exercise training leads to improved delivery and utilization of oxygen for energy production, sports performance and daily living (Rivera-Brown & Frontera, 2012). Review articles support the assumption that especially regular aerobic exercise training improves autonomic nervous system regulation (Achten & Jeukendrup, 2003; Aubert et al., 2003; Carter et al., 2003; Hautala et al., 2004, 2009). Previous research indicates that responses to regular exercise training are highly heterogeneous, showing VO_2max changes that range from 0–40% (Hautala et al., 2009). Contributing factors for individual differences in response to exercise training are training history (Carter et al., 2003), age, gender, race, baseline fitness level and baseline value of the HRV parameter high frequency (Hautala et al., 2009). It is suggested that heredity plays an important role for both response to aerobic exercise training and autonomic nervous system functioning (Hautala et al., 2009).

Aerobic exercise training and heart rate variability (HRV)

Regular heart rate fluctuations are primarily due to changes in both parasympathetic and sympathetic control of the heart (Carter et al., 2003). Researchers have questioned the roles played by the intrinsic heart rate, the enhanced vagal tone to the sinus node and the sympathetic nervous system for they have consistently found resting bradycardia after aerobic exercise training (Hautala et al., 2009; Sandercock, Bromley, & Brodie, 2005; Sloan et al., 2009). The latter two possible mechanisms of influence are displayed in HRV measures (Achten & Jeukendrup, 2003).

Cross-sectional laboratory as well as ambulatory studies show that HF is higher in well-trained males and females (Hautala et al., 2009), indicating high parasympathetic activity. For sympathetic activity, the results are inconsistent, varying from lower to similar or even higher sympathetic activity in trained versus untrained individuals (Hautala et al., 2009). While most randomized, controlled trials have shown an increase in HRV parameters (Earnest, Lavie, Blair, & Church, 2008; Sandercock et al., 2005), a few did not support these results (Tuomainen, Peuhkurinen, Kettunen, & Rauramaa, 2005; Uusitalo, Laitinen, Väisänen, Länsimies, & Rauramaa, 2004). Hautala et al. (2004) reported increases in all frequency domain measures after 8 weeks of controlled training during day and night using ambulatory 24h measures. Furthermore, HF remained significantly higher after follow-up with home-based, self-surveilled training sessions that differed in intensity and frequency between participants. Similar results have been found in healthy sedentary adults (Hautala et al., 2003; Tulppo et al., 2003). Moreover, Earnest, Lavie, Blair, and Church (2008) found improvements in all time and frequency domain measures (except LF/HF) in 373 postmenopausal women after 6 months of training. Young adults seem to be more responsive to changes in HRV values in response to aerobic exercise training than elderly people (Aubert et al., 2003).

In sum, one of the reasons why regular exercise is protective for the cardiovascular system is an enhanced vagal tone, which can be seen in improved or maintained HRV (Joyner & Green, 2009). Besides the physiological adaptations to exercise, there are several positive effects on psychological well-being. The following section specifically describes affect-related effects of exercise, because they are relevant for the current thesis.

Aerobic exercise and affect

Regular aerobic exercise has been shown to reduce self-reported depressive symptoms in non-clinical and clinical populations (Blumenthal et al., 2009; Salmon, 2001) and increasing evidence has emerged showing that aerobic exercise is equally effective compared to pharmacological treatment for major depressive disorder (Blumenthal et al., 2009). Furthermore, regular exercise reduces state and trait anxiety (Petruzzello, Landers, Hatfield, Kubitz, & Salazar, 1991; Wipfli, Rethorst, & Landers, 2008), decreases negative affect, and increases positive affect (Arent, Landers, & Etnier, 2000; Reed & Buck, 2009; Salmon, 2001). Acute bouts of low and moderate exercise increase positive affect (Reed & Ones, 2006), while high intensity exercise exceeding the anaerobic threshold is related to negative affect, a consequence presumed aversive to sedentary individuals (Backhouse, Ekkekakis, Bidle, Foskett, & Williams, 2007; Ekkekakis, Backhouse, Gray, & Lind, 2008; Ekkekakis, Parfitt, & Petruzzello, 2011). In general, people with low baseline exercise levels and low baseline affect have a higher potential for improvement (Reed & Buck, 2009; Salmon, 2001).

Increasing evidence has also emerged for the association between unstructured physical activity and affect in healthy populations in daily life (Bossmann, Kanning, Koudela-Hamila, Hey, & Ebner-Priemer, 2013; Gauvin, Rejeski, & Norris, 1996; Kanning, Ebner-Priemer, & Brand, 2012; Schwerdtfeger, Eberhardt, & Chmitorz, 2008). Poole et al. (2011) found that objectively assessed physical activity was associated with daily positive emotional style and depressed symptoms of the previous two days. Recent evidence suggests that exercise of low and moderate intensity is effective for increasing affect (Ekkekakis et al., 2008; Schwerdtfeger et al., 2008).

The reasons for mood-enhancement through exercise are less clear. It has been suggested that they are independent from fitness because improvements, for example, were found in participants′ anxiety levels after low intensity exercise, and the effects of regular and acute exercise are similar (Reed & Buck, 2009; Steinberg et al., 1998). Several explanations have been proposed: Accumulated acute mood effects may be responsible but are questioned because exercise is likely aversive, especially at the beginning of training. Studies show that exercise can inhibit emotional responses prior to stressors (e.g., coping with exercise) and lead to attenuated responses shortly afterwards (Salmon, 2001). An alternative explanation is a long-term process. Salmon proposed a model that is based on the known anti-depressive and anxiolytic effects, partly aversive but hedonic properties, especially after extended training and reduced sensitivity to stress: with repetition of exercise the originally aversive tone is replaced by tolerance ultimately leading to a positive hedonic tone (Salmon, 2001). Furthermore, in contrast to psychological stressors that are often accompanied by perceived loss of control, exercise is a controllable stressor. Besides the behavioral adaptations, physiological adaptations emerge. Noradrenergic systems have been suggested for the antidepressant effects of exercise while opioid activation is reported in terms of affective improvement (Salmon, 2001). Β-endorphin, an endogenous opioid, appears to be responsible for the euphoric effect of running (runner´s high) but beta-endorphin levels are associated rather with negative affect than positive affect (de Geus & Stubbe, 2007). Since monoaminergic systems are involved in depression and anxiety they may partly explain exercise-induced mood enhancement (de Geus & Stubbe, 2007).

1.3.4 Exercise and physiological stress response

Research indicates that the effects of regular exercise on health can buffer the deleterious effects of stress on health (Gerber & Pühse, 2009; Hamer, 2012). Regular exercise is a physiological stressor that induces adaptations which are similar to those that take place during psychological stress. The cross-stressor adaptation hypothesis suggests that a stressor of sufficient intensity, induces adaptations in the physiological stress response system that reappear under other similar stressors (Sothmann et al., 1996). More specifically, it suggests that, in terms of a specific improved-response adaptation, regular exercise induces decreased physiological responses to physiological stressors. Furthermore, the adaptation processes are not limited to physiological stressors but also induce generalized decreased physiological responses under psychological stressors (Sothmann et al., 1996). Studies consistently show decreased responses to the same exercise challenge, illustrated by lower circulating hormone levels of the two physiological stress pathways, the hypothalamic-pituitary-adrenocortical axis (HPA) and the locus-ceruleus-sympathetic-adrenomedullary (LCSA) system (Sothmann, 2006). In addition, a cellular biosynthesis and storage of key endocrines and neurotransmitters has been observed. This habituation to the stressor exercise appears to be a precondition for the cross-stressor adaptation hypothesis (Sothmann, 2006) which suggests that regular exercise modifies the physiological response to psychological stress. Another aspect of the cross-stressor adaptation hypothesis has suggested two theoretical perspectives that may apply to exercise: First, chronic exercise increases the maximal capacity of stress responses under threatening conditions and enhances the efficiency under submaximal familiar challenges. Second, the stimulus threshold is changed for exercise as well as nonexercise stressors (Sothmann, 2006).

Over recent decades, numerous studies have empirically investigated the cross-stressor adaptation hypothesis, mostly by comparing the physiological reactivity of physically fit versus unfit people to mental stress tasks (Albright, King, Barr Taylor, & Haskell, 1992; Calvo, Szabo, & Capafons, 1996; Childs & de Wit, 2014; de Geus, van Doornen, & Orlebeke, 1993; Jackson & Dishman, 2006; Klaperski, von Dawans, Heinrichs, & Fuchs, 2013; Rimmele et al., 2007, 2009; Spalding, Jeffers, Porges, & Hatfield, 2000). Unfortunately, reviews and meta-analyses revealed inconsistent results in these previous studies (de Geus et al., 1993; Forcier et al., 2006; Gerber & Pühse, 2009; Jackson & Dishman, 2006; Sothmann, Hart, & Horn, 1991). While two meta-analyses found evidence for diminished physiological stress reactivity to psychological stressors in physically fit and exercising individuals (Crews & Landers, 1987; Forcier et al., 2006), another meta-analysis (Jackson & Dishman, 2006) did not indicate empirical support for reduced reactivity. Specifically, Forcier et al. (2006) reported decreased physiological reactivity, heart rate (HR), and systolic blood pressure to psychological stressors in physically fit versus unfit individuals including cross-sectional and longitudinal studies. In contrast, Jackson and Dishman (2006) did not present any support for reduced physiological stress reactivity but rather empirical evidence for improved physiological recovery after psychological stress. The discrepancies between even a few randomized, controlled trials speak to the lack of a consensus on this topic. While some studies found decreased physiological stress reactivity (Holmes & Roth, 1988; Klaperski, von Dawans, Heinrichs, & Fuchs, 2014; Spalding, Lyon, Steel, & Hatfield, 2004), others did not demonstrate differences in physiological stress reactivity between control and experimental groups (Albright et al., 1992; de Geus et al., 1993; Lindgren et al., 2013; Sloan et al., 2011). Hamer, Taylor, and Steptoe, (2006) reviewed 15 randomized, controlled trials of acute exercise sessions and identified a reduction of blood pressure in response to laboratory stressors. The authors suggested that regular exercisers are often in a post-exercise window (characterized by hypotension) when they encounter stressors.

In sum, the results support the hypothesis that exercise induces reduced physiological stress reactivity due to higher parasympathetic activity and possibly less sympathetic activity (according to animal studies showing reduced norepinephrine response; Hamer et al., 2006), but results are inconsistent due to methodological shortcomings (for example, baseline values), small sample sizes, many different stress tasks and stress measures (e.g., blood pressure, heart rate, different parameters of HRV). The results also indicate that the effect of regular exercise on physiological stress responses is highly variable between persons.

1.3.5 Exercise and emotional stress response

Psychology research indicates that emotional and physiological stress reactivity may differ (Campbell & Ehlert, 2012) however, psychological responses to stress have been examined less extensively than physiological responses. There are several theoretical models illustrating that exercise is supposed to affect the stress process at different points (de Geus & Stubbe, 2007; Fuchs & Klaperski, 2012), but none of the models can explain exactly how exercise affects emotional stress response. Emotional responses to stress have been assessed rather as a side product in addition to physiological stress reactivity in cross-sectional and longitudinal studies using laboratory stress tasks. While some studies have shown reduced emotional stress reactivity (Anshel, 1996;

Childs & de Wit, 2014; Klaperski et al., 2013; Rimmele et al., 2007; Throne, Bartholomew, Craig, & Farrar, 2000) others did not find any support for reduced emotional stress reactivity (Julian, Beard, Schmidt, Powers, & Smits, 2012; Rimmele et al., 2009). More important, emotional responses to laboratory stress tasks are usually assessed during the anticipation phase and shortly after the stress test. While anticipation measures are questioned per se for representing baseline measures (Balodis, Wynne-Edwards, & Olmstead, 2010), retrospective emotional assessments after the stress exposure are subject to recall bias. Furthermore, the emotional involvement is supposed to be minimal in laboratory compared to real-life stress situations (Campbell & Ehlert, 2012).

1.3.6 Exercise and stress during real life

The few studies examining the association between exercise and real-life stressors demonstrated encouraging results. Specifically, Ritvanen, Louhevaara, Helin, Halonen, and Hänninen (2007) showed that aerobic fitness was associated with reduced HR and perceived stress during work in teachers. Brooke and Long (1987) found that lower HR levels were maintained in fit compared to unfit subjects during rappelling. Finally, men with higher VO_2max showed lower HR in response to a “guerilla slide”, a stressful military real-life task (Wittels, Rosenmayr, Bischof, Hartter, & Haber, 1994). Studies examining emotional responses during real-life stressors reported an inverse relationship between perceived stress and exercise and an inverse relationship between negative affect and exercise (Giacobbi, Hausenblas, & Frye, 2005; Giacobbi, Tuccitto, & Frye, 2007; Steptoe, Kimbell, & Basford, 1998). While no study examined the effects of regular exercise training on emotional stress reactivity during real-life, one study addressed the effects of a 6-month exercise intervention in combination with a weight-loss program on physiological responses during the daily routine of hypertensive individuals (Steffen et al., 2001). Participants of the exercise intervention group showed significantly lower blood pressure during subjectively-rated levels of low stress and low physical activity, but not during levels of high stress and high physical activity. No study examined the effects of regular exercise on both emotional and physiological stress responses during real-life stress.

1.3.7 Ambulatory Assessment

Although laboratory studies deliver important insights under controlled conditions, several authors have argued that studies conducted in the laboratory may reveal effects with smaller size or the outcomes may not be comparable to real life at all, principally due to the non-personally relevant stressors and the artificial setting (Gauvin et al., 1996; Schwartz, 2003; Sloan et al., 2011; H. Wilhelm, Grossman, & Müller, 2012; Zanstra & Johnston, 2011) To improve ecological validity, physiological processes, physical activity, and self-reported psychological variables (e.g. perceived stress, positive/negative affect) can be assessed in real life using ambulatory assessment (Fahrenberg, Myrtek, Pawlik, & Perrez, 2007; Trull & Ebner-Priemer, 2013). Furthermore, with continuous physiological monitoring and repeated psychological and context assessments the dynamic changes of stress can be captured in real time. The term *Ambulatory Assessment* serves as a methodological umbrella for a wide range of assessment methods to study individuals in their natural environment, including self-report, observational and biological, physiological and behavioral methods (Trull & Ebner-Priemer, 2013).

The previous sections illustrate that stress presents a prominent health risk factor. While previous research focused on either physiological or emotional stress responses, it becomes clear that physiological and emotional stress responses can differ within a person thus both should be considered. As psychology research increasingly focused on minor daily hassles and chronic psychological stress, the importance of emotional effects of daily stress became apparent (Bolger & Schilling, 1991). Besides the indirect effects of exercise on stress due to training-induced physical adaptations and improved psychological well-being, exercise is suggested to reduce emotional and physiological stress responses. Unfortunately, studies have mainly used non-personally relevant stressors and artificial settings (laboratory) and mainly cross-sectional study designs to examine exercise-induced stress responses. To date, results only partly support the assumption that exercise reduces physiological and emotional responses to stress. Although emotional responses to daily stress are important, little is known about the effects of regular exercise training on emotional responses.

The few recent cross-sectional studies using real-life stressors, demonstrate encouraging results. However, they do not allow us to draw causal conclusions. It is still unclear whether regular exercise leads to lower physiological stress responses to psychological stressors or if people with a favorable psychological profile tend to exercise more (de Geus & Stubbe, 2007). In addition, a recent longitudinal study showed that stress can lead to reduced exercise behavior in relation to stages of change while adopting an active lifestyle (Lutz, Stults-Kolehmainen, & Bartholomew, 2010; Stults-Kolehmainen & Sinha, 2014). People in lower stages of change rather reduced their exercise behavior, while people in higher stages of change responded with higher exercise levels. Thus, randomized, controlled trials are required to draw causal conclusions about how regular exercise influences emotional and physiological stress responses in real life. Although habitual physical activity appears to be important for the stress-exercise association, previous studies did not control for habitual activity levels or used retrospective self-report measures, which are subject to recall bias (Prince et al., 2008).

The present thesis poses the inquiry that prior laboratory research studies have not been able to clearly answer: Can regular exercise lead to reduced emotional and physiological stress responses? Using a randomized, controlled trial design, the aim of the current thesis is to examine the effects of regular aerobic exercise training on physiological and emotional responses during real-life stress (academic examinations). Using ambulatory measures to assess physiological processes, physical activity, and self-reported psychological variables (e.g., perceived stress) in participants´ natural environment, the current thesis aims to improve ecological validity (Trull & Ebner-Priemer, 2013).

1.4 Study Design

Data were collected during two study periods (6 months each) over the winter semesters (October 2011 to March 2012 and October 2012 to March 2013). Sixty-one sedentary male electrical engineering students from the Karlsruhe Institute of Technology (KIT) volunteered to participate in the study and signed informed consent. Participants were randomized to either control or aerobic exercise training group, and stratified by habitual exercise habits and previous activity history. Participants of the experimental group attended 20 weeks of aerobic exercise training with two running sessions every week from the beginning of the semester until the end of the academic examination period. At the beginning, running sessions lasted about 30 min and included walking phases of 2 min. Besides a continuous increase in duration of training (3 min per week), intensity was progressively increased by adding intervals of 3 and 4 min in zone II after Week 4. The students completed two real-life assessment periods, a baseline and a stressful period. The pre-intervention baseline assessment was set to the beginning of the semester because it represents a regular academic period where students experienced low stress (Loft et al., 2007). The academic examination period was used as the real-life stressful episode given that academic examinations are a real-life demand that induces noticeable stress in students (Hazlett, Falkin, Lawhorn, Friedman, & Haynes, 1997; Nguyen-Michel, Unger, Hamilton, & Spruijt-Metz, 2006). To assess physiological responses, ambulatory ECG and physical activity (accelerometry) were monitored continuously during the two assessment periods (for two days each). Using electronic diaries, subjective self-reported perceived stress and mood were assessed repeatedly every two hours during baseline and stressful episodes. Additional context information (consumption behavior, time, location, social contact, activity) was obtained via electronic diaries, too. Aerobic capacity (VO_2max) was assessed pre- and post-intervention via cardiopulmonary exercise testing.

2 The activity-affect association in inactive people

Published as

von Haaren, B., Loeffler, S. N., Haertel, S., Anastasopoulou, P., Stumpp, J., Hey, S., & Boes, K. (2013) Characteristics of the activity-affect association in inactive people: an ambulatory assessment study in daily life. *Frontiers in Psychology, 4*:163. doi: 10.3389/fpsyg.2013.00163.

2.1 Abstract

Acute and regular exercise as well as physical activity (PA) is related to wellbeing and positive affect. Recent studies have shown that even daily, unstructured physical activities increase positive affect. However, the attempt to achieve adherence to PA or exercise in inactive people through public health interventions has often been unsuccessful. Most studies analyzing the activity-affect association in daily life, did not report participants´ habitual activity behavior. Thus, samples included active and inactive people, but they did not necessarily exhibit the same affective reactions to PA in daily life. Therefore the present study investigated whether the association between PA and subsequent affective state in daily life can also be observed in inactive individuals. We conducted a pilot study with 29 inactive university students (mean age 21.3 yrs ± 1.7) using the method of ambulatory assessment. Affect was assessed via electronic diary and PA was measured with accelerometers. Participants had to rate affect every two hours on a six item bipolar scale reflecting the three basic mood dimensions energetic arousal, valence and calmness. We calculated activity intensity level (mean Metabolic Equivalent (MET) value) and the amount of time spent in light activity over the last 15 min before every diary prompt and conducted within-subject correlations. We did not find significant associations between activity intensity and the three mood dimensions. Due to the high variability in within-subject correlations we conclude that not all inactive people show the same affective reactions to PA in daily life. Analyzing the PA-affect association of inactive people was difficult due to little variance and distribution of the assessed variables. Interactive assessment and randomized, controlled trials might help solving these problems. Future studies should examine characteristics of affective responses of inactive people to PA in daily life. General assumptions considering the relation between affect and PA might not be suitable for this target group.

2.2 Introduction

The relationship between physical activity (PA) and different affective states has been studied for decades. Early studies focused on the association between acute and regular exercise on specific negative affective states such as depression and anxiety (Ekkekakis & Petruzzello, 1999). There is evidence that exercise reduces self-reported negative affective states, namely anxiety and depression (Arent et al., 2000; Landers & Arent, 2001; Rethorst, Wipfli, & Landers, 2009; Wipfli et al., 2008). Later studies integrated a rather dimensional approach of affect including positive and negative affective states.

Reed and Ones (2006) published a review about the effects of acute exercise on positive activated affect. People with lower pre-exercise affect values had higher increases in positive activated affect. Low intensity as well as moderate and vigorous exercise increased post exercise affect, with the highest observed increase in low intensity exercise. The increase of positive activated affect in response to low and moderate doses of exercise seems to be generalizable, with low intensity having the highest effect sizes (d= 0.57). There is more variability in affective responses to high intensity exercise. Both short and long bouts of acute exercise can induce affective improvements; however exercises lasting longer than 75 min seem to decrease positive affect. Even short bouts of brisk walking can increase activation and positive affect (Ekkekakis, Hall, VanLanduyt, & Petruzzello, 2000). Exercise intensity seems to have an important impact on post exercise affect and future adherence to exercise. Based on several study results, the dual mode theory was developed to show that valence declines beyond the aerobic-anaerobic transition (Ekkekakis & Acevedo, 2006). The authors claimed that affective states have to be assessed more frequently during exercise because affective states during exercise may explain the variability in post exercise affective states as response to high intensity exercise. Their assumption was confirmed by recent studies showing that especially inactive people show higher affective states if exercise intensity is moderate. In addition, it was recently shown that self-selection of activity intensity may help to identify the activity intensity that fits best for an individual to increase affect (Ekkekakis et al., 2011).

Considering the effects of regular exercise on positive activated affect, research draws a similar picture, regular aerobic exercise increases positive affect (Berger & Motl, 2000; Ekkekakis et al., 2000; Reed & Buck, 2009). Participants with lower baseline positive affect values had larger increases in positive affect. The highest effects were found for high and low intensity exercise programs. In contrast to the variance of affective reactions to acute sessions, repeated high intensity exercise seems to, maybe due to physiological and psychological adaptations, reach a similar level of affective changes as low intensity exercise (Reed & Buck, 2009). Additionally, the positive affective changes observed in regular exercise programs seem to be independent of training response and fitness changes (Ekkekakis et al., 2000) and the magnitude of effects was similar in acute and regular exercise (Reed & Buck, 2009; Reed & Ones, 2006).

While earlier studies focused on the potential of acute and regular exercise to improve affect, PA in daily life has become an important issue. Current activity guidelines promote daily PA and accumulated short bouts (duration of 10 min) of daily PA to be health effective (Haskell et al., 2007). As a consequence interventions recently started to include the promotion of single short bouts of activity to become more active. Thus, a growing number of studies try to examine whether PA in daily life also has the potential to improve positive affect (Hyde, Conroy, Pincus, & Ram, 2011; Kanning et al., 2012; Kanning & Schlicht, 2010; Poole et al., 2011; Schwerdtfeger et al., 2008; Wichers et al., 2012).

Hyde et al. (2011) showed that people who were more physically active in general had higher pleasant activated feelings than less active people. Moreover, higher levels of pleasant activated feelings arose on days people were more active than typical for them. Kanning and Schlicht (2010) examined 13 older adults and revealed that subjectively reported activities in daily life increased energetic arousal and calmness. The authors assumed that PA is able to modify mood if there is a low baseline level but is not able to induce changes if mood state is already high.

To assess the relationship between affective states and PA in daily life, ambulatory assessment studies seem to be an appropriate method. Earlier studies mainly used retrospective self-report measures of affect and PA which are vulnerable to recall bias (Ebner-Priemer & Trull, 2009). Ambulatory assessment involves repeated respectively continuous sampling of current behavior and emotional reactions in real time. Thus, this approach allows the capturing of individual variability in affective responses to physical activities. Thereby it provides the potential to identify responders and non-responders that cannot be detected by means of the group aggregate considering the fact that one individual does not always react the same way (Backhouse et al., 2007; Shiffman, Stone, & Hufford, 2008). Additionally subjective self-reports of physical activities tend to overestimate activity and correlations between objective and subjective measures are low to moderate (Bussmann, Ebner-Priemer, & Fahrenberg, 2009; Prince et al., 2008). Ambulatory assessment has the potential to measure PA occurring in daily life quite accurately via accelerometers. Furthermore self-reported affective states as well as contextual information can be assessed *in situ*. (Bussmann et al., 2009; Fahrenberg et al., 2007).

Kanning et al. (2012) did an ambulatory assessment study with 44 university students. They assessed PA continuously via accelerometry, affective states and the relative autonomy index were conducted with electronic diaries every 45 min for one day. They replicated the findings of Kanning and Schlicht (2010) for the valence and energetic arousal dimension being higher due to higher PA. In contrast to Kanning and Schlicht (2010) the calmness dimension was negatively correlated with PA. In addition, autonomous regulation moderated the PA-affect association

Another ambulatory monitoring study in 24 healthy participants (aged 18-73 years) assessed the relation between PA and mood in daily life. Schwerdtfeger et al. (2008) recorded PA for one day and assessed positive activated and negative affect every hour via PDAs. They showed significant effects of PA (5, 10 and 15 min before PDA prompt) on positive activated affect, but not on negative affect. Even low-intensity walks predicted higher positive activated affect.

Wichers et al. (2012) examined the effects of PA on positive and negative affective states in a large sample of 504 people. PA and affect were both assessed subjectively with electronic diaries. Participants had to state the current context (activity, location, social contact) and affect every 90 min on five consecutive days. Higher activity levels indicated higher subsequent levels of positive affect, but not of negative affect.

Affect is assumed to be an important motivator for continuing and maintaining PA (Dishman, 1990). Despite the postulated *feel better effect* of acute and regular exercise as well as PA in daily life, drop outs in exercise interventions are high and adherence to regular exercise and PA is low. More than half of our population is inactive (Centers for Disease Control and Prevention, 2008). For example, less than half of the US population meets the current PA guidelines (Haskell et al., 2007) and the problem can be seen worldwide (B. E. Ainsworth, 2009; Bauman et al., 2009). Sedentary behavior is an increasing health risk in our society (Owen, Sparling, Healy, Dunstan, & Matthews, 2010).

Latest research showed that people can suffer from metabolic and cardiovascular health risk factors or diseases if they have prolonged sedentary episodes, even if they achieve the activity guidelines (M. Hamilton, Hamilton, & Zderic, 2007; Koster et al., 2012; T. Warren et al., 2010).

As a consequence, one of the main public health goals currently is the interruption of these long sitting times through performance of light activities. Light intensity activity was beneficially associated with resources against health risks (M. Hamilton et al., 2007). Light activities contribute to overall energy expenditure, but do not count for achieving the activity guidelines yet. Reducing prolonged sitting time through sedentary breaks calls growing attention as potential “easy to introduce intervention” in everyday life and has been shown to have beneficial impact on health (Brown, Bauman, & Owen, 2009; Healy et al., 2008; Owen, Healy, Matthews, & Dunstan, 2010). Based on the evidence that not only exercise but also PA in daily life is health preventive, the question whether PA in daily life also has the potential to increase affect was studied more intensively. The importance to reduce long sitting times in addition to be active raises the question whether light activities performed to interrupt prolonged sitting offer the potential to increase affect in daily life.

There is growing evidence in low intensity activity being effective for health and mental well-being (Camhi, Sisson, Johnson, Katzmarzyk, & Tudor-Locke, 2011; Ekkekakis et al., 2008, 2000; M. Hamilton, Hamilton, & Zderic, 2004). Inactive people may also profit from low intensity exercise (Bixby & Lochbaum, 2006; Carels, Berger, & Darby, 2006). Daley and Welch (2003) found that sedentary inactive people had the highest affect ratings during low intensity exercise.

Unstructured PA in daily life includes a lot of low intensity physical activities such as walking from one place to another. There is consensus of different scientific fields that affect plays a central role in decision making (Baumeister, Vohs, DeWall, & Zhang, 2007) and this also seems to be suitable for the decision to engage in PA and exercise (Carels et al., 2006). Based on a finding of Simonen et al. (2003), Ekkekakis, Hall, and Petruzzello (2005) interestingly assumed that there is a “genetically determined pleasure-based mechanism that has evolved to reward and promote physical activity”. Moderate activities (intensities below the lactate threshold) made up most of people´s time for hundreds of years to ensure surviving (Ekkekakis et al., 2005). Along with the industrialization, the increasing sedentariness induced obesity and a reduced fitness level, too. (Ekkekakis et al., 2005) assume that, in combination with factors as muscular and skeletal aches, as well as cognitive factors and physical ineffectiveness, affective responses to moderate intensity have changed negatively. Thus, it is possible that the pleasure-based mechanism to reward and promote PA is light but not moderate activity for inactive people.

If low intensity PA increases positive affect, sedentary people might choose such activities to increase PA levels in daily life. Sedentary persons might perceive low intensity activities as less aversive compared to high intensity activities (Daley & Welch, 2003). Interventions to promote low intensity activity in daily life such as enhancing the accumulation of short bouts of activity or reducing longer periods of sedentary behavior by sedentary breaks may induce different affective reactions. Schwerdtfeger et al. (2008) found that the higher the BMI of participants, the higher was the association between PA in daily life and energetic arousal/positive affect. They assumed that obese people may be able to influence more positively energetic arousal, which is generally lower in this population. The study did not take into account habitual PA as a moderator of the relation between affect and PA in daily life. Thus one cannot conclude that the results found in obese people can automatically be transferred to sedentary people but there is a close link between sedentariness and obesity.

In conclusion, research shows that acute and regular exercise has the potential to enhance positive affect and these effects partly apply for sedentary people (Bixby & Lochbaum, 2006; Carels et al., 2006).

The exercise intensity seems to be an important issue considering adherence and dropout rates from exercise programs of sedentary people. Studies show that sedentary people prefer exercises of lower intensity compared to active people and exercise of lower intensity can improve affective states (Ekkekakis et al., 2011). In addition, ambulatory assessment studies showed that unstructured PA in daily life can increase affect. These studies account for the importance of inter-individual differences and perceptions for activities inducing increases in affect. In addition, an individual´s affect in response to PA in daily life can be captured in many different situations. High positive affective states after PA in daily life were observed especially for light and moderate activities. Out of the studies that analyzed the association between unstructured PA in daily life and affective states, none examined sedentary people or controlled fitness and habitual PA level. As habitual exercise participation can mediate affective responses to acute bouts of exercise (Hallgren, Moss, & Gastin, 2010), this may also be appropriate for habitual PA.

Unstructured PA of moderate and light intensity in daily life may be a better opportunity to achieve and maintain higher activity levels in inactive people than exercise. In addition recent research shows that reducing prolonged sedentary episodes through performance of light activities is important besides achieving current activity guidelines.

Thus this pilot study aimed at providing new insights in the PA-affect association of inactive people in daily life. Because we were interested in affective states after PA in different situations of an individual in real life, we used the method of ambulatory assessment. We hypothesized that PA in daily life was associated with subsequent affective state in inactive people. Thus we analyzed how PA was associated with subsequent affective state.

In a secondary analysis, we addressed a possible association between interrupted sedentariness and affective states. To our best knowledge no study has yet examined whether breaks in prolonged sedentary episodes are associated with affective states in young inactive adults in daily life.

2.3 Methods

2.3.1 Participants

Twenty-nine students (mean age: 21.3 years ± 1.7; mean BMI: 24.5 ± 4.4) of the electrical engineering and information technology department (3rd and 5th semester) were recruited at a German university. They were informed about study goals and written consent was obtained according to the guidelines set for by our institution. All participants were inactive (being defined as exercising once a week or less) and had a mean relative VO_2max of 40.9 (± 5.6) ml/min/kg, measured *via* gas analysis during a progressive treadmill test.

2.3.2 Measures

Physical activity

PA was assessed with the Move II sensor (movisens GmbH, Karlsruhe, Germany) placed to the chest. Move II consists of a triaxial acceleration sensor (adxl345, Analog Devices) with a range of ±8 g, 64 Hz sampling frequency and 12 bit resolution. The measuring unit has an additional air pressure sensor (BMP085, Bosch GmbH) with a sampling frequency of 8 Hz and a resolution of 0.03hPa (corresponding to 15 cm at sea level). The recorded raw data was saved on a SD card and was transferred to a computer for further analysis via a USB 2.0 interface.

Based on the hypothesis, we operationalized PA in two ways. First we calculated mean activity intensity and energy expenditure expressed by the MET value. Using MET values is an established method to estimate and classify the energy cost of human PA. Activity intensity is displayed on the basis of their energy cost as multiple of 1 MET, which is defined as the energy cost of a person at rest (B. Ainsworth et al., 2011). Activities ranging from 1-1.5 MET are defined as sedentary, from 1.6-2.9 MET as light, 3-5.9 as moderate and ≥ 6 as vigorous (B. Ainsworth et al., 2011). Second, we calculated the min spent in the light activity category to analyze whether the proportion of time spent in light activities during the activity episode was associated with subsequent affect.

In the first step the activity was classified in intervals of 4 seconds. For further explanation of the activity recognition process see the publication of Anastasopoulou, Tansella, Stumpp, Shammas, and Hey (2012). The classification algorithm differentiated between the following 7 activities: lying, rest (sitting/standing), cycling, uphill, downhill, level walking and jogging. Based on the detected activity class, the appropriate activity-dependent EE model was selected and the EE was estimated. Input for the EE estimation models were the acceleration magnitude, the altitude change and some subject related parameters (sex, age, height and weight). MET was calculated as the ratio of the associated metabolic rate for the specific activity divided by the resting metabolic rate (RMR) (for details see FAO/WHO/UNU, 1985).

Affective state

For the assessment of affective states, MyExperience movisens Edition (movisens GmbH, Karlsruhe, Germany) was used to install the mood scale on the PDAs (personal digital assistant; HTC Touch Diamond 2) and to program time stamp and intervals between the diary prompts. We used a six item short scale (P. Wilhelm & Schoebi, 2007) which measures the three basic mood dimensions with two bipolar items for each dimension: energetic arousal (*E: tired-awake; full of energy-without energy*); valence (*V: content-discontent; unwell-well*) and calmness (*C: agitated-calm; relaxed-tense*). The scale was developed based on the Multidimensional Mood Questionnaire (Steyer, Schwenkmezger, & Eid, 1997) and validated especially for momentary assessment of mood in daily life (P. Wilhelm & Schoebi, 2007). Participants rated their current mood based on the statement “At the moment, I feel…” on a seven-point bipolar rating scale with two opposed adjectives as endpoints (0 to 6). Prior to analyses three items were reversely coded to ensure that higher scores indicated higher values of E, V, and C. Subscale scores for each dimension ranged from 0 (*low value*) to 12 (*high value*).

2.3.3 Procedure

The measurement equipment was handed out to the participants in an introductory session at the university one day prior to the start of the assessment period. PA was objectively conducted with the Move II accelerometer (movisens

GmbH, Karlsruhe, Germany) over 12 hours on two days (10 am-10 pm). Participants had to record the duration during which they did not wear the device. Ratings of affective states and activities were prompted via PDAs. Participants were alerted by the vibrating signal of the PDA approximately every two hours between 12 am and 10 pm with a random component to avoid subjects waiting for the signal. Subjects had to answer the prompts within 15 min, and if they missed a signal, they were reminded by two further signals after five and ten min. PDA morning entries (10 am) were excluded from the analyses because the accelerometer registration of PA started at 10 am, and analyzing the previous 15min of the 10 am PDA entry was, therefore, not possible. Additionally, the variable waking time of subjects caused numerous 10 am prompts to be missed. PDA and accelerometer time were synchronized by the initialization of the computer.

2.3.4 Data analyses

PDA prompts corresponding to non-wearing times of the activity sensor were excluded from the analyses. MET values were averaged across data points for each minute in a 12 hour period for both days (10:00 a.m.–10:00 p.m.).

To analyze the within-subject association between preceding PA and mood, the average PA intensity was calculated over the preceding 15 min before the PDA prompt. Based on recent studies, a 15 minute interval was chosen to include as much activity as possible but within a time frame that ensures that increased affect after activity would still be visible (Ekkekakis et al., 2000; Schwerdtfeger et al., 2008). The mean MET level was calculated by averaging MET values (per minute) of this time interval. To investigate the potential of light activities to increase affective states, we calculated min spent in light activities (1.6-2.9 MET). This level is the most performed activity of sedentary people. Thus, one might get more intervals of light activity compared to moderate or vigorous intervals, especially in an inactive sample. We summed up min spent in light activity over the 15 minute interval and did within-subject correlations for the three affect dimensions with light activity.

For the secondary analysis we calculated the number of sedentary breaks to reflect interruptions of at least one minute in sedentary time. Thus, one sedentary break reflected an interruption of sedentary behavior (≤ 1.5 MET) of at least one minute. To calculate breaks of sedentary periods, we used intervals of 30 min length.

For this pilot study within-subject correlations of the activity and affect variables were assessed to show the range of within-subject correlations in the sample. Due to the small sample size (N = 29) and the lack of variance in activity, as well as the distribution of the affect variables, we decided to take a more robust statistical method instead of using multilevel analyses. Therefore we calculated the within subject-correlations between activity variables (mean MET, min spent in light activity and sedentary breaks) and the three dimensions (valence, energetic arousal and calmness) of affect. To calculate the mean correlation coefficient, we did Fisher's z- transformation to convert Pearson's r values into normally distributed z values. The mean correlation coefficient was transformed back via inverse fisher´s z. Significance (p) was tested via t distribution (Bortz & Schuster, 2010).

2.4 Results

2.4.1 Association between activity intensity/minutes spent in light activity and affect

Three hundred thirty-four data points for activity variables and corresponding affective state variables were available. Across all 15 minute intervals, participants had a mean activity intensity level of 1.44 (± 0.42) MET. Participants spent on average 1.62 (± 2.46) min in light activity across all 15 minute intervals. Across all 15 minute intervals, participants spent 86% in sedentary behavior, 10.4% in light activities and 3.6% in moderate to vigorous activity. The activity spent during the 15 min intervals was significantly associated to overall measured PA (two days) for both mean MET level (r = 0.724; p = <.001) and min spent in light activity (r = 0.710; p =.00). Mean affective states were 7.44 (± 2.41) for energetic arousal, 8.78 (± 1.94) for valence and 8.74 (± 2.2) for calmness. Participants rated the two measurement days as either quite (3) or predominantly (4) typical (on a scale ranging from 1 *not at all* to 5 *absolutely*).

By calculation of 90th and 10th percentiles, we identified that 80% of the data points of E were located between the affect scale scores of 4 and 10, and 80% of V and C were located between the scores 6 and 11 (Table 1.1). The calculation of 10th and 90th percentiles for both mean MET level (10th = 1.25; 90th = 1.94) and min spent in light activity (10th = 0; 90th = 5) showed that most of the time was spent in an intensity reflecting primarily sedentary behavior (see Table 1.1; Figure 2.1).

Table 1.1: Means, standard deviations and 90th and 10th percentile of all activity and affect variables

Variable	***M* (±*SD*)**	***10th percentile***	***90th percentile***
Mean MET	1.45 (± 0.42)	1.25	1.94
Min Sedentary	13.39 (± 3.75)	8	15
Min Light	1.63 (± 2.46	0	5
Min Moderate	0.51 (± 1.38)	0	2
Min Vigorous	0.04 (± 0.51)	0	0
Sedentary Breaks	5.05(± 5.8)	0	14
Energetic Arousal (E)	7.44 (± 2.41)	4	10
Valence (V)	8.78 (± 1.94)	6	11
Calmness (C)	8.74 (± 2.2)	6	11

Note. Mean MET, min spent in sedentary, light, moderate and vigorous activity variables are summarized across 15 min intervals.

None of the affect variables, E, V, and C, showed significant associations to the activity intensity level precedent to the affect assessment (Table 1.2), with energetic arousal showing the highest mean correlation coefficient for both activity variables, mean MET-level (r = 0.17; p = .82) and min spent in light activity (r = 0.13. p = .75). The within-person correlations between energetic arousal (E) and mean MET level ranged from r = -0.42 to 0.89. To illustrate the number of persons having low, high negative or high positive correlation coefficients, the results of the correlations were categorized (1 = 0.3-0.99; 0 = -0.29-0.29; -1 = -0.3- (-0.99)). 16 subjects had a correlation coefficient between 0.29 and -0.29, 10 subjects had a correlation coefficient of 0.3 to 0.99 and 3 subjects fell into category -1 (-0.3 to -0.99). The within person-correlations for the association between min spent in light activity and E ranged from r = -0.42 to 0.93 (see Table 1.2). Participants rated higher as well as lower energetic arousal when they spent little time in light activity. Low ratings of E together with high numbers of min spent in light activity did not occur.

Table 1.2: Correlation coefficient (*r*), range, significance and effect sizes of within-subject correlations between mean activity intensity and mood dimensions

Variable	***R***	***Range***	***t***	***p***	***r²***
mean MET_E	0,17	-0,42-0,88	0,92	0,82	0,03
mean MET_C	-0,09	-0,90-0,52	-0,45	0,33	0,01
mean MET_V	-0,03	-0,97-0,67	-0,13	0,45	0,00
min_light_E	0,13	-0,42-0,93	0,69	0,75	0,02
min_light_C	-0,08	-0,94-0,35	-0,44	0,33	0,01
min_light_V	0,08	-0,93-0,94	0,40	0,65	0,01
sed_breaks_E	0,20	-0,57-0,82	1,04	0,85	0,04
sed_breaks_C	-0,08	-0,81-0,70	-0,42	0,34	0,01
sed_breaks_V	0,07	-0,83-0,85	0,38	0,65	0,00

Note. Correlation coefficient (*r*) of within subject correlation (*N*= 29; *df*= 27) between mean activity intensity (mean MET during15 min interval) and E (energetic arousal), C (calmness) and V (valence); amount of min spent in light activity (during 15 min interval) and E, C, V; sedentary breaks (during 30 min interval) and E, C, V; range of within-subject correlations; significance (*p*); effect sizes (r^2)

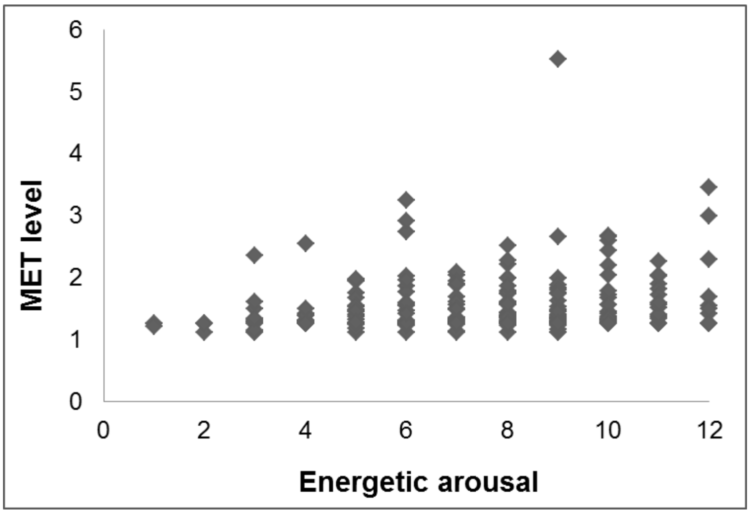

Figure 2.1: Scatter plot of E (energetic arousal) score and activity intensity (mean MET level during 15 min interval)

The results of the within-person correlations of the two other mood dimensions, valence and calmness, showed even lower correlation coefficients (Table 1.2). Within-subject correlations between valence and mean MET level ranged from -0.97 to 0.67, (min light: *r* = -0.93-0.94). The within-subject correlations between calmness and mean MET ranged from -0.90-0.52, (min light *r* = -0.94-0.35). Participants rated higher as well as lower affective scores (valence, calmness) when they spent little time in light activity. Low ratings of affective states together with high numbers of min spent in light activity did not occur (see Figure 2.2).

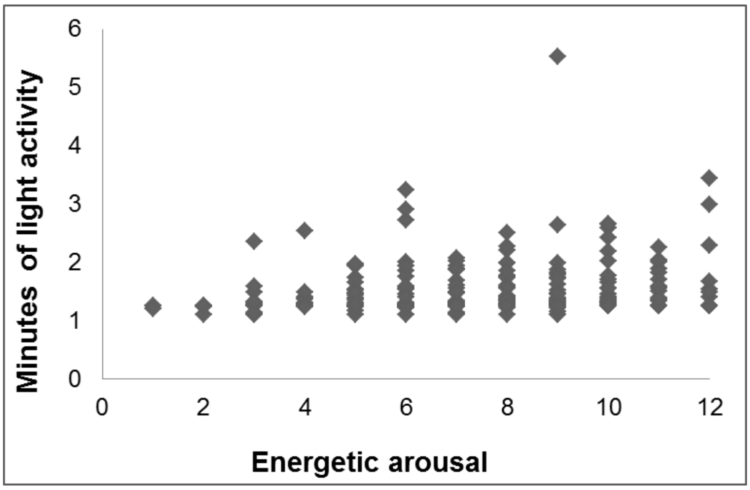

Figure 2.2: Scatter plot of E (energetic arousal) score and amount of min spent in light activity (during 15 min interval)

2.4.2 Secondary analysis: association between sedentary breaks and affect

Across all 30 minute intervals, the mean number of sedentary breaks was 5.1 (± 5.8). The scatter plot shows that few as well as lots of sedentary breaks during the 30 minute interval induced higher as well as lower arousal states. Participants did not have low arousal states and a high number of sedentary breaks at the same time (see Figure 2.3).

Again energetic arousal showed the highest correlation with sedentary breaks (*r* = 0.2, *p* = .85) with a range of within-subject correlations from -0.57 to 0.82, but did not reach significance. Valence and calmness were not related to sedentary breaks (Table 1.2).

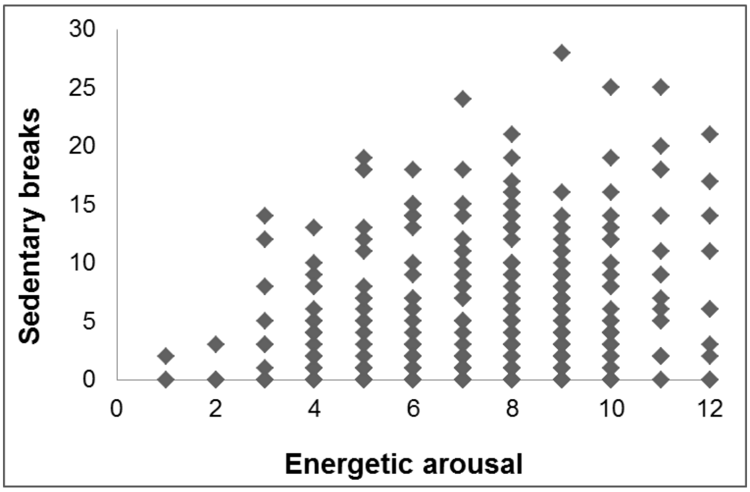

Figure 2.3: Scatter plot of E (energetic arousal) score and sedentary breaks (during 30 min interval)

2.5 Discussion

In the present pilot study we investigated whether the PA intensity level of inactive young adults was associated with affective states in daily life. Moreover, we were interested whether affective states of inactive young adults changed in response to the amount of time spent in light activities. Our results are not in direct agreement with earlier studies demonstrating a relationship between PA and positive affect in daily life (Hyde et al., 2011; Kanning et al., 2012; Kanning & Schlicht, 2010; Schwerdtfeger et al., 2008; Wichers et al., 2012). We found small and statistically insignificant associations between energetic arousal and activity intensity level as well as low intensity activity. The two other affect dimensions, valence and calmness were not related to PA.

Despite the variety of variables used to display activity (active versus inactive episodes, number of counts, milli-g) and the fact that other studies did not control habitual activity or fitness level of participants (or did not report it), it seems adequate to assume that our sample was more inactive compared to samples of former studies. (Kanning & Schlicht, 2010) registered 28% of active episodes and 72% of inactive episodes, compared to 86% inactive and 14% active (mainly light activities) episodes in this study. Kanning et al. (2012) reported 77.3 milli-g/min compared to the mean MET level of 1.44 MET in the present study (reflecting the sedentary behavior category).

Compared to earlier studies, we extended our analysis to two days. Thus, we reduced the risk for picking an untypical day, but reduced the chance to capture activity episodes by programming PDA prompts every two hours (compared to every hour).

The distribution of the valence and calmness dimension variables was shifted to high positive affective state scores. It is possible, that for people having general high mood scores, PA is less effective in altering mood. Kanning and Schlicht (2010) as well as Gauvin et al. (1996) discuss ceiling effects as a possible explanation and studies show stronger improvement in affect if the baseline level is low (Reed & Ones, 2006). The constant high valence and calmness levels of subjects in this study may partially explain the lack of finding an activity-affect relation.

The results of the present pilot study highlight the difficulty of analyzing the relation between affect and PA of inactive people. It is difficult to relate affective states to active episodes if they hardly appear during the day (Ebner-Priemer, Koudela, Mutz, & Kanning, 2013). We anticipated the difficulty to capture a lot of vigorous and moderate activity episodes, but we did not expect that even light activity episodes would hardly occur in the present study. Of the 334 data points, only 60 had a mean MET level > 1.6. The calculation of the 10^{th} and 90^{th} percentiles illustrated the immense lack of variance of the activity data, thus the data was insufficient to detect associations.

To solve the problem of identifying less frequent appearing behavior, interactive assessment is a promising approach for future studies. The methodology of interactive monitoring was developed by (Myrtek, 2004). Ebner-Priemer et al. (2012) introduced an algorithm for the analysis of the activity-affect relation. Diary signals can be triggered by an algorithm, developed for interactive monitoring, when a predefined activity threshold is surpassed. This method has the potential to quadruple the e-diary assessments during activity episodes compared to the method of this study (Ebner-Priemer et al., 2013).

Recently few authors claimed to analyze affective states not only pre and post but during exercise, because it is not yet determined whether during exercise-affect or post-exercise-affect plays a greater role for future adherence to exercise and activity (Backhouse et al., 2007). Interactive monitoring offers the potential to meet the demand of exercise psychologists to measure affective states not only before and after exercise but also during exercise. Specific activities inducing positive affective states during an activity might be suitable for the promotion in daily life.

As sedentariness holds high risk factors for several diseases (M. Hamilton et al., 2007; Owen, Sparling, et al., 2010; J. Warren et al., 2010) one of the main public health goals is getting sedentary people more active and achieve sustained active lifestyles. As current activity guidelines (Haskell et al., 2007) promote an increase in accumulated short bouts of PA in daily life, more studies examined the appearance of this behavior. Affect may influence one`s behavioral intention, (Baumeister et al., 2007). Thus intensities, activities and types of activity improving an individual's affect may lead to future repetition of the behavior.

Based on the current literature one can assume that low intensity activities as often performed in daily life, can increase positive affect (Ekkekakis et al., 2008, 2000). Low intensity activities can increase affective states in sedentary inactive people because they experience them as less aversive than high intensity activities (Bixby & Lochbaum, 2006; Carels et al., 2006; Daley & Welch, 2003). In addition, they are easy to perform in daily life. Thus sedentary people might choose such activities to increase PA levels in daily life. The present study revealed a high inter- and intra-individual variability in affective responses to light intensity activity. This is in line with the claim of some authors to account for inter-and intra-individual variability and the dual mode theory (Backhouse et al., 2007). Due to the lack of active episodes no distinct conclusions can be drawn.

Randomized, controlled trials increasing PA episodes and therefore data points to analyze may be a promising approach to get more insights into the daily life activity-affect relation of inactive people. To promote low intensity activity in daily life, for example, enhancing the accumulation of short bouts of activity or reducing longer periods of sedentary behavior by sedentary breaks may induce different affective reactions. Based on results of their study, Schwerdtfeger et al. (2008) assumed that obese people have the potential to increase energetic arousal through PA of daily life. This assumption should be taken into account when continuing research of the activity-affect association of inactive people in future projects based on the present study. Daily life activities having the potential to increase arousal (for example short walks) should be promoted by interventions and the effectiveness can be assessed by ambulatory assessment.

The present study has several limitations that should be discussed. The lack of moderate to vigorous activity episodes might reflect that assessing affect every two hours over two days and relating it to the preceding 15 min before the PDA prompt may not be the method to choose in any sedentary sample. To get more active episodes, more days and more affect prompts have to be conducted. Another option to capture more active episode is looking for an active episode and relate it to the subsequent affect rating.

Clearly for the analysis of this ambulatory assessment study considering the association between PA and affect in daily life, multilevel analysis would be the common statistical method to use. It offers the potential to identify both within-subject and between-subject variability. Additionally, one can control confounding variables like contextual variables, habitual PA of subjects, and PA of the subsequent activity interval after the PDA prompt, etc. Due to the sample size, insufficient variance of the activity variables and the distribution (not normally distributed) of the valence and calmness variable in the present pilot study, we decided to calculate within-subject correlations instead of multilevel analyses. In addition, we wanted to take a special look on within-subject correlations.

However, there are some important aspects this study illustrates. The wide range of within-subject correlation coefficients seems to underline the responder-non responder discussion or the consideration of the inter-individual affective reaction to PA in the activity-affect paradigm (Backhouse et al., 2007). It means that there might not only be one activity intensity, duration, and type of activity that enhances affective states. Every individual and its contextual situation might induce different reactions and different preferences of activity characteristics (as dose, duration and type). Moreover, the low intraclass correlations in some participants illustrate, that some individuals´ affective response to PA differed from situation to situation. Both the inter- and intra-individual variability the present study revealed are in line with the concept of the dual mode theory. Interestingly, if participants were inactive, they showed high as well as low affective state scores, but lower affective states did not occur together with people being more active.

In conclusion, the present study attempted to address the potential of daily life activity to increase affective states of inactive people. The difficulty to capture active episodes of inactive people to identify which activities increase affect illustrated a general paradox. How can we assess which physical activities in daily life are useful for inactive people if they hardly perform any PA? Randomized, controlled trials increasing PA in daily life, might solve this problem. However, inactive people probably do not like to be active, thus affective states might be negatively influenced by this aversion against activity. Future studies have to assess whether low intensity exercise and self-selected activities in daily life are less aversive to inactive people and thus useful to enhance activity in daily life.

3 Regular exercise and emotional stress reactivity

Published as

Von Haaren, B., Haertel, S., Stumpp, J., Hey, S., & Ebner-Priemer, U. W. (2015). Reduced emotional stress reactivity to a real-life academic examination stressor in students participating in a 20-week aerobic exercise training: A randomized, controlled trial using Ambulatory Assessment. *Psychology of Sport and Exercise. 20*, 67-75. 10.1016/j.psychsport.2015.04.004.

3.1 Abstract

Objectives: To examine if a preventive 20-week aerobic exercise intervention (AET) can improve emotional stress reactivity during real-life stress.

Design: Randomized, controlled trial; within-subject design.

Method: Sixty-one inactive students were randomly assigned to a waiting control and an AET group. To capture the situation-specific, intra-individual data in real life, electronic diaries were used. Participants reported their moods and perceived stress (PS) repeatedly over two days during their daily routines pre- and post-intervention. The pre-intervention baseline assessment was scheduled at the beginning of the semester, and the post-intervention assessment was scheduled at a real-life stressful episode, an academic examination. For the aerobic fitness assessment, both groups completed a cardiopulmonary exercise test on the treadmill before and after the intervention. Multilevel models (MLMs) were conducted to compare within- and between-subject associations.

Results: Significant emotional stress reactivity was evident in both groups during all assessment periods. However, participants in the AET group showed lower emotional stress reactivity compared with their control counterparts after the 20-week training program during the real-life stress episode (the academic examination).

Conclusions: AET conferred beneficial effects on emotional stress reactivity during an academic examination, which is likely an extremely stressful real-life situation for students. Aerobic exercise training appears to be a promising strategy against the negative health effects of accumulated emotional stress reactivity.

3.2 Introduction

Research in psychology has found that reactivity to daily life stress is not only determined by a physiological response but also can be defined as a covariation of stress and affect (Sliwinski, Almeida, Smyth, & Stawski, 2009). Perceived daily life stressors, such as excessive demands at work, have an immediate effect on physical and emotional functioning (Van Eck, Nicolson, & Berkhof, 1998; Zautra, Affleck, Tennen, Reich, & Davis, 2005). For example, the risk of depression and cardiovascular disease increases through the accumulated effects of daily stress (Cacioppo et al., 1998; Carels et al., 2000; van Eck, Berkhof, Nicolson, & Sulon, 1996). Enhanced emotional reactivity to real-life stress reflected by Negative Affect (NA) predicts physiological (Salovey, Rothman, Detweiler, & Steward, 2000; van Eck et al., 1996, 1998) diseases and higher vulnerability to psychotic disorders (Collip et al., 2013; Myin-Germeys et al., 2001). Patients with psychosis showed increased emotional sensitivity to smaller disturbances in daily life (Myin-Germeys, Krabbendam, Delespaul, & van Os, 2003). In addition, the emotional component of stress reactivity plays an important role in future stress appraisals (Lazarus & Folkman, 1984).

Physical activity and exercise offer the potential to reduce the risk of stress-induced mental and physical diseases (Warburton, Katzmarzyk, Rhodes, & Shephard, 2007). Until now, the existing link between the health-enhancing effects of physical exercise and the phenomenon of stress has been mostly explained by the so-called *stress-buffer hypothesis* (Gerber & Pühse, 2009; Hamer, 2012; Sothmann, 2006; Tsatsoulis & Fountoulakis, 2006), which is based on the assumption that the positive health effects of physical activity and fitness serve as a moderator in the relationship between stress and health. In terms of stress reactivity, researchers have mainly examined the physiological parameters (heart rate variability, heart rate, cortisol) of fit versus unfit individuals at baseline and during mental stress tasks in laboratories (de Geus & Stubbe, 2007; Forcier et al., 2006; Gerber, 2008; Jackson & Dishman, 2006; Sothmann, Hart, & Horn, 1991). Because psychology research indicates that emotional and physiological stress reactivity may differ (Campbell & Ehlert, 2012), it is also important to assess emotional stress reactivity. However, existing research that considers the association between exercise and emotional stress reactivity has a number of limitations.

First, most studies have used laboratory-induced stress tasks, and the results of both cross-sectional studies (Klaperski et al., 2013; Rimmele et al., 2007, 2009) and randomized, controlled trials are inconsistent (Anshel, 1996; Calvo et al., 1996; Goldin, Ziv, Jazaieri, Hahn, & Gross, 2013; Julian et al., 2012; Throne et al., 2000; Zanstra & Johnston, 2011). In a recent cross-sectional study that used the Trier Social Stress Tests (TSST), a laboratory stress test that is more related to naturalistic stressors, Klaperski et al. (2013) found greater decreases in mood in young women who exercised compared with women who did not exercise in response to the TSST. Using a similar study protocol, Rimmele et al. (2009) reported contradictory findings, namely, higher anxiety and lower mood levels in untrained compared with trained men. Puterman et al. (2011) found that activity levels moderated the relationship between rumination and cortisol levels in response to acute stressors, suggesting that active people may be protected against stress-induced rumination. Although laboratory studies deliver important insights under controlled conditions, they often do not result in the same outcomes as those from naturalistic settings (Gauvin et al., 1996; H. Wilhelm et al., 2012).

Second, previous randomized, controlled trials used single retrospective pre/post self-report measures of NA and global measures of PS (Baghurst & Kelley, 2014; de Geus et al., 1993; Norris, Carroll, & Cochrane, 1992). However, psychological variables such as stress and affect are fluctuating constructs that change over the course of time (Stone, Smyth, Pickering, & Schwartz, 1996). Moreover, the patterns of responses to daily stressors may vary (Bolger & Schilling, 1991). Thus, repeated real-time assessments of PS and affective states during different situations across contexts represent the dynamic nature of the subjective stress experience more accurately than single pre/post assessments (Lazarus, 2000; Poole et al., 2011; Schlotz et al., 2008).

Finally, the few conducted field studies are cross-sectional and focus on the associations between acute exercise and emotional stress reactivity in daily life (Giacobbi et al., 2005, 2007; Steptoe et al., 1998). For example, Giacobbi et al. (2007) asked university students about their daily exercise, conducted threat appraisals in response to stressful events and assessed positive/negative affect via an internet platform during an examination period. During the most stressful days, exercise was significantly related to increased positive affect (PA). In addition, exercise led to decreased NA when events were appraised as being threatening; however, NA increased with accompanied exercise when events were appraised at higher threat levels. In another study, Giacobbi et al. (2005) showed that exercise and daily life events were both independently associated with PA. Increased levels of exercise led to increases in PA on days with more positive and more negative events. Steptoe et al. (1998) found fewer perceived stressful events on exercise days compared with non-exercise days among regular exercisers with low trait anxiety and higher PA on exercise days compared with non-exercise days. Another daily life study showed that walking time during the evening was inversely correlated with perceived stress (PS) ratings before going to sleep, and walking time during the afternoon was inversely correlated with negatively evaluated high activation during the evening (Hallman & Lyskov, 2012). None of the studies addressed the effects of regular exercise on emotional stress reactivity during real life.

To date, there has been a need for inexpensive strategies that are easy to use and effective at preventing the development of mental disorders, such as depression. The potential of exercise as a strategy to reduce the negative effects of repeated enhanced emotional reactivity to real-life stress is still unclear. To overcome the shortcomings of previous studies, we conducted a randomized, controlled trial using Ambulatory Assessment. The term “Ambulatory Assessment” encompasses a wide range of methods used to study people in their natural environments, including momentary self-reports, ecological momentary assessments, and observational and physiological methods (Trull & Ebner-Priemer, 2013).

To investigate if a preventive 20-week aerobic exercise intervention could lower emotional stress reactivity during real life, we compared the emotional stress reactivity of students who were participating in aerobic exercise training with a control group (CG) pre- and post-intervention. To maximise within-subject differences in stress reactivity and to demonstrate the treatment effect, we chose the following two real-life assessment periods: We set the pre-intervention baseline assessment to the beginning of the semester because we assumed that students had low stress at this time. The post-intervention assessment was set to the end of the semester (the examination period) and was used as the real-life stressful episode given that academic examinations are a real-life demand that induces noticeable stress in students (Hazlett et al., 1997; Nguyen-Michel et al., 2006).

3.3 Methods

3.3.1 Participants

Sixty-one inactive (≤ 1x moderately active for 60 min/week) male electrical engineering students (M_{age} = 21.4, *SD* = 1.6) were recruited during the semester's first week of lectures. The sample came from two phases (each with 30 participants) that lasted for one winter semester (October 2011 to March 2012 and October 2012 to March 2013). After the study, participants attended a lecture on the potential of exercise to reduce stress. We addressed only subjects in their 3rd or 5th semesters of university studies because they sat for similar exams. Thus, we achieved similar conditions during academic examinations for all participants. To recruit participants, we informed the students about the study during lectures in the first week of the semester. Interested students signed up to be contacted via email to receive an invitation to the study kick-off meeting. Every student received information about the study, and eligible participants who wanted to participate gave written informed consent. Students did not receive financial compensation, but they did receive credits in their courses if they completed all measurements and attended the lecture and the intervention (experimental group).

3.3.2 Measures

The present study was conducted using Ambulatory Assessment, which is the method used for repeated sampling of subjective psychological variables in real time and in the natural environment (Trull & Ebner-Priemer, 2013). All psychological variables were assessed via electronic diaries, which were kept in the Touch Diamond 2 (HTC Germany GmbH, Frankfurt, Germany). Using the software MyExperience movisens Edition (movisens GmbH, Karlsruhe, Germany), mood and stress scales were installed on the diaries, and time stamps and intervals between diary prompts were programmed. Participants answered the questions presented on the diary screens by choosing the appropriate number on the presented scales using the integrated diary touch pen.

Perceived stress

To account for work-related strains during the academic examinations, acute PS was operationalized via one item that assessed perceived control, following earlier studies (Fahrenberg, Brügner, Foerster, & Käppler, 1999; Rau, Georgiades, Fredrikson, Lemne, & de Faire, 2001; Rau, 2004). Participants answered the question “Is the present situation under your control?” on a 7-point Likert scale (1 = *not at all* to 7 = *absolutely*).

Mood

To assess the current mood state, we applied a short six-item scale based on the Multidimensional Mood Questionnaire (MDMQ; Steyer, Schwenkmezger, & Eid, 1997) that is validated especially for Ambulatory Assessment (Wilhelm & Schoebi, 2007). The scale measures three basic mood dimensions, valence (V: *content-discontent*; *unwell-well*), calmness (C: *agitated-calm; relaxed-tense*) and energetic arousal (E: *tired-awake; full of energy-without energy*), with two items. Wilhelm and Schoebi (2007) reported within-person (V, C = .70; E = .77) and between-person (V = .92; C, E = .90) reliability levels. Participants had to rate their current moods based on the statement ‘At the moment I feel…’ on a 7-point scale (0 = *not at all* to 6 = *very*) with opposing adjectives as endpoints. To ensure that higher scores indicated higher values for V, E, and C, we recoded the three negatively pooled items into positive ones prior to analysis.

Aerobic capacity

Maximum oxygen consumption (VO_2max) is the central parameter for determining aerobic capacity. To be able to detect the effects of exercise on emotional stress reactivity, an effective intervention reflected by significantly enhanced VO_2max was required. Thus, as a manipulation check to assess aerobic capacity, VO_2max was determined through cardiopulmonary exercise testing (MetaMax 3B, cortex-biophysik) on a treadmill until exhaustion, with an initial pace of 6 km/h, a continuous slope of 1% and an increase of 2 km/h per stage every three min (Roecker, 2007). Heart rate was recorded continuously using POLAR heart rate monitors (RS800). Within a standardized interruption of 20 seconds between stages, an arterial blood sample was taken from the participants’ hyperaemic earlobe into a 20 µl end-to-end capillary to analyse blood lactate. At the end of each stage, participants rated their perceived exertion scores (RPE) on the Borg Scale from 6–20 (Borg, 1982). All participants achieved a respiratory exchange ratio (RER) of ≥ 1.1 and a heart rate of at least 220 beats minus age (T. Meyer & Kindermann, 1999), and all were appraised as exhausted by an experienced instructor. Thus, for all participants, the achievement of VO_2max was assumed. The RER reflects the ratio between the amount of carbon dioxide produced (VCO_2) and the oxygen consumed (VO_2) during one breath.

3.3.3 Procedure

At the beginning of the study, participants were randomized to a control and an aerobic exercise training group, stratified by their habitual physical activity levels, which were assessed via questionnaire (Bös et al., 2009; Jekauc, Wagner, Kahlert, & Woll, 2013). This study used a wait-list control group; thus, participants who were randomized to the CG received aerobic exercise training after the end of the study. We conducted the cardiopulmonary exercise pretest (CET_{pre}) during the first two weeks of the study (start of the semester) prior to the AET group intervention. After the completion of the pretests (November 1st), the AET for the experimental group began. After 3.5 months of AET (see Figure 3.1), we conducted the cardiopulmonary exercise post-test (CET_{post}) with exactly the same procedure as the pretests. Participants completed the post-tests prior to the exam period to avoid any influence on their performance.

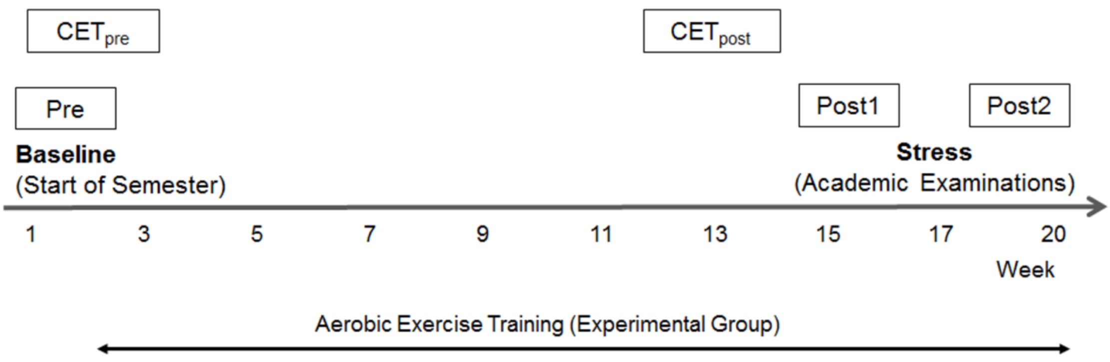

Figure 3.1: Illustration of the study design: Timeline with pre- and post- assessments of emotional stress reactivity, cardiopulmonary exercise testing and the duration of the exercise intervention

Emotional stress reactivity was assessed pre- and post-intervention for two days each. To maximize within-subject differences in stress reactivity and to demonstrate the treatment effect, we chose the following two real-life assessment periods: We set the pre-intervention baseline assessment to the beginning of the semester because we assumed that students had low stress at this time. The post-intervention assessment was set to the end of the semester (the examination period) and was used as the real-life stressful episode given that academic examinations are a real-life demand that induces noticeable stress in students (Hazlett et al., 1997; Nguyen-Michel et al., 2006). To increase representativeness, we conducted measurements twice during the academic examination period. The time span between the exam and the end of data recording was restricted to at least one and a maximum of two days. Participants chose their first measurement episode (post1) during the first weeks of the exams (weeks 2/3), and the second episode (post2) took place during the middle of the exams.

Participants initialized the first diary prompt of the day when they turned on the diary after awakening. Except for the morning prompt, all diary prompts were initialized automatically by a vibrating signal every two hours with a varying incidence of the signal of one to five min to prevent participants from waiting for the signal. Thus, all diary prompts occurred between 10 a.m. and 10 p.m. If participants missed a signal, reminders were sent after 5, 10, and 15 min. If participants did not answer the last reminder, the prompt was recorded as missing, and the next signal occurred with the next prompt approximately two hours later.

3.3.4 Intervention

Participants in the experimental group attended a 20-week aerobic running training course. The intervention lasted until participants passed both measurement times during the academic exams. In addition to VO_2max, the main outcomes of the cardiopulmonary exercise test were maximum running speed, lactate threshold and individual anaerobic threshold. Based on these, we calculated individual heart rate zones for each participant (zone I: aerobic; zone II: aerobic-anaerobic) using the software Ergonizer® (Sports medicine, Freiburg,

K. Röcker) and installed the training schedules and the heart rate target zones on the RS800 heart rate monitors. Skilled exercise science students supervised and instructed the running groups of 7–8 people using the standardized training schedule. Participants completed the training in a group and wore the heart rate monitors to record their training and meet their individual heart rate requirements. To allow for individual but group-based running sessions, the training sessions took place outdoors in an area close to the campus with fixed trails. Training sessions took place during lunch time to allow for short routes and little time loss. Students had to complete two training sessions every week. At the beginning, running sessions lasted approximately 30 min and included walking phases of 2 min. Separate from the continuous increase in training duration (3 min/week) over time, intensity was progressively increased by adding intervals of 3 and 4 min in zone II after week four. Compliance with the intervention was very good in every training group, with no dropouts during the intervention.

3.3.5 Data analysis

To determine whether the aerobic exercise intervention had successfully improved the AET group's aerobic capacity, we conducted an analysis of covariance (ANCOVA) with VO_2max_{rel} after the intervention as the dependent variable (CET_{post}), VO_2max_{rel} prior to the intervention as the covariate (CET_{pre}) and group (CG/AET) as the treatment factor.

Our repeated assessments of psychological variables during the baseline (pre) and during the exam period (post1 and post2) resulted in data of a hierarchical structure with multiple observations of NA and PS (level 1) nested within persons (level 2). We applied Multilevel models (MLMs) to differentiate between within-subject and between-subject effects and their interactions. In addition, MLMs allow for a different number of observations between participants and provide model estimates even for individuals with missing data (Hoffman & Rovine, 2007). We used IBM SPSS Statistics 20 for Windows to estimate the effects of the independent variables (PS, group and interaction of PS and group) on the dependent variable NA. We ran MLMs for the baseline (pre) and both post1 and post2.

To obtain the NA variable, we recoded the valence dimension (V) as follows: (0 = 4; 0.5= 3.5; 1 = 3; 1.5 = 2.5; 2 =2; 2.5 = 1.5; 3 = 1; 3.5 = 0; 4 = 0; 4.5 =0; 5= 0; 5.5 = 0; 6 = 0). Prior to additional analyses, PS was reverse coded to better illustrate NA; thus, higher values indicated higher PS. To account for individual differences in mean stress, PS was person-mean centered by subtracting the mean PS value across all observations per person from each observation of the person. Group was coded as a dummy variable as either 0 (*CG*) or 1 (*AET group*). The following equation displays the integrated form as well as the level 1 and level 2 components of our model separately:

$$NA_{ti} = \Upsilon_{00} + \Upsilon_{10} \cdot WithinPerson_{perceived\ stress} + \Upsilon_{01} \cdot Group + u_{0i} + \Upsilon_{11} \cdot Group \cdot WithinPerson_{perceived\ stress} + \varepsilon_{ti}$$

$$Level\ 1: Y_{ti} = \beta_{0i} + \beta_{1i} \cdot WithinPerson_{perceived\ stress} + \varepsilon_{ti}$$

$$Level\ 2: \beta_{0i} = \Upsilon_{00} + \Upsilon_{01} \cdot Group + u_{0i}$$

$$\beta_{1i} = \Upsilon_{10} + \Upsilon_{11} \cdot Group$$

Level 1 represents the participants' responses (subscript i) as reported on the NA scale (Y_{ti}) in any given diary entry (subscript t). Y_{ti} is a function of the individual intercept β_{0i}, person i's average level of PS, β_{1i}, which is the effect of the within-person PS, meaning the increase in NA with every increase of PS, and ε_{ti} is the residual NA in a situation t for a person i. Finally, β_{0i} displays the effect of the group (level 2) on NA, and β_{1i} is the effect on NA of the cross-level interaction between group (level 2) and PS (level 1), that is, the effect of group on the extent of change in NA caused by the change in PS.

3.4 Results

3.4.1 Sample Characteristics

We excluded two participants from the analysis because they did not complete all three assessments (pre, post1 and post2). Participants in the AET and control groups did not differ in person characteristics or cardiopulmonary exercise testing parameters prior to the intervention (Table 2.1). Aerobic capacity, operationalized via VO_2maxrel, increased by 8.7% from pre- to post-intervention in the AET group and decreased by 5.6% in the CG (Table 2.1). The ANCOVA revealed significance for the factor group, VO_2maxrel: $F(1, 56) = 59.8$, $p < .001$, $\eta 2 = .52$, indicating a strong effect (J. Cohen, 1988) of the intervention on aerobic capacity.

Table 2.1: Means and standard deviations of person characteristics and results of the cardiopulmonary exercise test

	Pre		**Post**	
	AET	**CG**	**AET**	**CG**
Variable	*M (SD)*		*M (SD)*	
Age	21.3 (1.5)	21.5 (1.7)		
BMI	23.8 (3.5)	24.6 (4.9)		
Rel.VO_2max (ml/kg/min)	48.5 (6.5)	49.9 (6.7)	52.8 (6.4)	47.1 (7.3)
RER	1.14 (0.1)	1.14 (0.1)	1.2 (0.1)	1.21 (0.1)
HR_{max} (beats/min)	199.8 (7.8)	201.8 (8.8)	197.7 (8.1)	199.8 (7.9)

Note. CG = control group; BMI = Body Mass Index; CET = cardiopulmonary exercise testing; Rel.VO_2max = maximal oxygen consumption in ml per kilogram bodyweight per minute; RER = Respiratory Exchange Ratio; HR_{max} = maximum heart rate.

Compliance

At the baseline (pre), there were 28 missing data points (2.7%); at post1, 94 out of 960 data points were not answered (9.7% missing); and at post2, 80 out of 944 data points were missing (8.5%). We had data that indicated that during the examination period, students in general woke up later than 11 a.m. and missed the first prompt; thus, we appraised compliance as being good in the present study.

For our analysis, 944 NA and PS data points were available at pre, post1 and post2. Except for the two students who were withdrawn from the analyses, data from both measurement times during the examination period were available for each participant. Unconditional NA models revealed that average NA was 0.24 at pre, 0.25 at post1 and 0.28 at post2. Intraclass coefficients were $\sigma = 0.02$ for pre, σ = 0.41 for post1 and σ = 0.21 for post2, indicating that intra-individual variation caused 98%, 59% and 79% of the variance, respectively.

3.4.2 Emotional stress reactivity at baseline

Descriptively, participants of the CG reported slightly higher PS at baseline (pre) compared with the AET group, while values of NA were similar between the groups (Table 2.3). The MLMs revealed that higher PS (level 1) significantly predicted higher NA, whereas neither the group (level 2) nor the cross-level interaction of group×PS predicted NA at baseline (Table 2.2). Thus, emotional stress reactivity was evident at baseline, but did not differ between the groups.

3.4.3 Emotional stress reactivity during academic examinations

Descriptively, the participants' average PS ratings increased from baseline to post1 during exams, and the increase was similar in both groups (see Table 2.3). Although PS was similar during both exam periods (post1 and post2) in the AET group, it increased further from post1 to post2 in the CG. In contrast to the similar baseline NA levels in both groups, the CG showed higher NA at post1 and post2, whereas the AET group rated slightly lower NA at post1 compared with baseline and similar NA compared with baseline at post2. MLMs of the within-subject effects (level 1) revealed that PS (person-mean centered) significantly predicted NA (Table 2.2). Conditions of higher PS than the person mean related to higher NA ratings, and thus emotional stress reactivity was evident.

Table 2.2: Results of the multilevel models for NA as the dependent variable at every time of measurement

	Pre			**Post1**			**Post2**		
Variable	β	*SE*	*t*	β	*SE*	*t*	β	*SE*	*t*
Intercept	0.25***	0.04	5.86	0.33***	0.08	3.93	0.35***	0.08	4.60
PS	0.21***	0.03	7.24	0.24***	0.03	7.89	0.38***	0.03	10.75
Group	-0.02	0.06	-0.46	-0.16	0.11	-1.35	-0.13	0.11	-1.19
PS×Group	-0.05	0.04	-1.17	-0.11*	0.05	-2.33	-0.18***	0.05	-3.55

Note. PS = perceived stress; Pre = Baseline; Post1 = first academic exam assessment; Post2 = second academic exam assessment
* p < .05. *** p < .001

Between-subject effects revealed that during both episodes of academic exams (post1 and post2), the coefficients for the predictor group (level 2) were negative and higher compared with the baseline findings. These results descriptively indicated that AET group participants had lower NA at post1 and post2 (see Table 2.2) compared with the CG. However, group affiliation did not significantly predict NA during the exams.

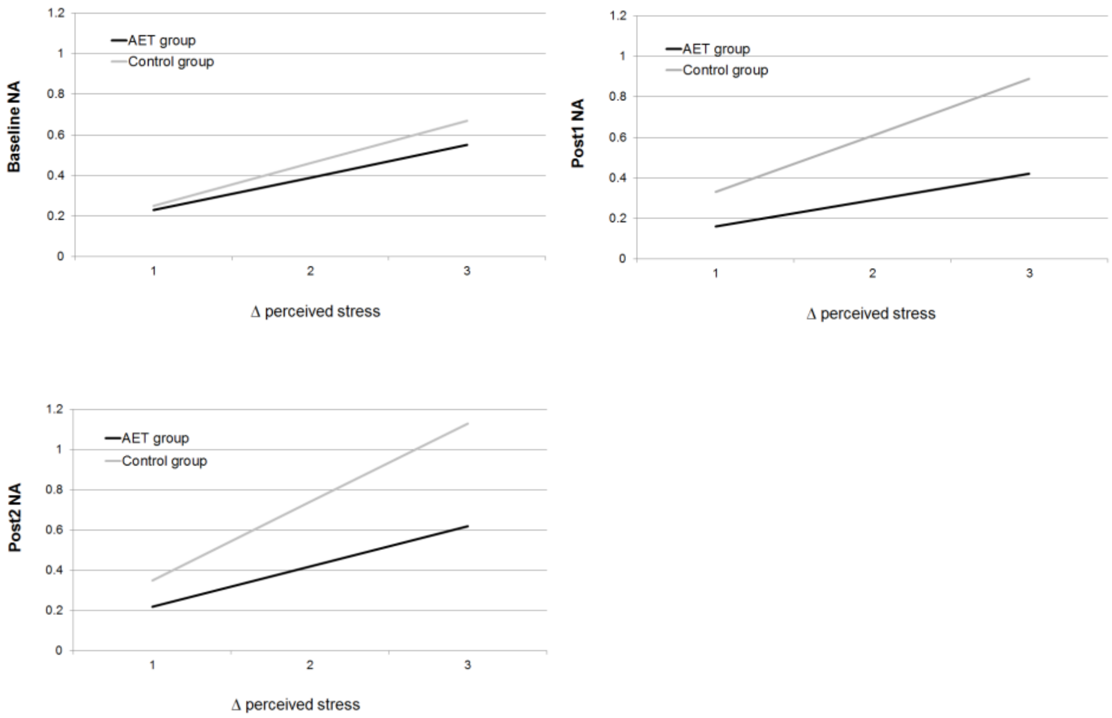

Figure 3.2: Emotional stress reactivity (predicted values) by group at baseline (pre) and at both examination periods (post1 and post2). NA = Negative Affect.

In the next step, we added the cross-level interaction between group and PS to the model. This interaction significantly predicted NA. NA values differed between groups, especially when participants perceived stress that was higher than their person-specific means. Table 2.3 shows that the coefficient for the group×PS interaction was negative (variable coded as control group = 0), indicating that the AET group reacted with less NA in situations of higher PS during the exams and thus had lower emotional stress reactivity (Figure 3.2). Although this interaction did not predict NA at baseline, it was a significant predictor of NA at post1. At post2, the cross-level interaction of group×PS was again a significant predictor of NA (Table 2.2; Figure 3.2). Thus, after the 20-week aerobic exercise intervention, AET group participants showed lower emotional stress reactivity to both academic episodes (post1 and post2). At post2, the coefficient for the group×PS interaction in the model was higher compared with post1 (Table 2.2), descriptively indicating a larger effect of the group×PS interaction at post2 (Figure 3.2).

Table 2.3: Means, standard deviations, minimum and maximum of the psychological variables at each time of measurement

	AET			CG		
Variable	*M (SD)*	*Min*	*Max*	*M (SD)*	*Min*	*Max*
Pre						
PS	2.06 (0.66)	1.40	3.40	2.20 (0.82)	1.34	4.00
NA	0.23 (0.42)	0.00	1.30	0.26 (0.49)	0.0	1.50
E	3.81 (1.04)	1.95	5.30	3.60 (1.13)	1.48	5.16
V	4.36 (0.82)	2.70	5.41	4.35 (0.91)	2.48	5.51
C	4.42 (0.78)	2.83	5.38	4.47 (0.90)	2.47	5.63
Post1						
PS	2.27 (0.58)	1.57	3.37	2.43 (0.56)	1.62	3.41
NA	0.17 (0.35)	0.00	1.10	0.34 (0.39)	0.09	1.26
E	4.11 (0.84)	2.58	5.22	3.89 (1.02)	2.02	5.28
V	4.39 (0.74)	2.80	5.38	4.23 (0.71)	2.79	5.20
C	4.35 (0.68)	3.02	5.27	4.27 (0.73)	2.93	5.29
Post2						
PS	2.24 (0.61)	1.67	3.33	2.51 (0.59)	1.59	3.62
NA	0.22 (0.30)	0.00	0.93	0.35 (0.43)	0.00	1.24
E	4.23 (0.79)	2.65	5.25	3.87 (0.98)	2.03	5.19
V	4.33 (0.62)	3.12	5.18	4.22 (0.77)	2.85	5.35
Ce	4.21 (0.64)	2.95	5.12	4.25 (0.73)	2.97	5.34

Note. PS = perceived stress; Pre = Baseline; Post1 = first academic exam assessment; Post2 = second academic exam assessment; V = valence; E = energetic arousal; C = Calmness; PS = perceived stress; NA = negative affect.

3.4.4 Secondary Analyses

Descriptively, the mean values of the three mood dimensions valence, calmness and energetic arousal showed different characteristics in the AET group versus the CG during the non-stressful and examination periods. Mean valence was similar between baseline and both stress periods (post1 and post2) in the AET group. In addition, valence was higher compared with the CG during both examination periods (Table 2.3), but the MLMs did not reveal significance for the predictor group (Table 2.2). Although the result was not statistically significant, mean energetic arousal was even higher in the AET group compared with the CG during the stressful period (Table 2.3). Descriptively, the decrease in calmness from baseline to post1 was lower in the AET group than the CG (Table 2.3).

To analyze the effects of the group×PS interaction on energetic arousal, calmness and valence, we calculated single models for each of the three dimensions. Because higher values indicated higher calmness, energetic arousal and valence, the interpretation is more complex. PS significantly predicted valence, calmness and energetic arousal at all times of measurement (Table 2.4). Thus, participants who rated as having lower PS had higher valence, calmness and energetic arousal ratings. In addition, the analyses revealed a marginally significant effect of the group×PS interaction on valence at post1, which achieved significance at post2 (see Table 2.4). The results indicate that under increased PS, the experimental group rated greater valence than did the CG. In addition, at post1, the group×PS interaction significantly predicted calmness. Under increased PS, the experimental group rated more calmness than did the CG (Table 2.4), although this result was not confirmed at post2. No significant group×PS interaction was found for energetic arousal.

Table 2.4: Results of the Multilevel Models for the three Mood Dimensions as the Dependent Variables at every Time of Measurement

Valence Model									
	Pre			**Post1**			**Post2**		
Variable	β	*SE*	*t*	β	*SE*	*t*	β	*SE*	*t*
Intercept	4.35***	0.11	39.73	4.23***	0.15	27.38	4.22***	0.16	26.69
PS	0.44***	0.04	9.76	0.45***	0.05	9.28	0.59***	0.05	12.78
Group	0.01	0.15	0.19	0.16	0.21	0.74	0.11	0.22	0.48
PS×Group	-0.00	0.07	-0.01	-0.13	0.07	-1.84	-0.24***	0.07	-3.59
Calmness Model									
	Pre			**Post1**			**Post2**		
Variable	β	*SE*	*t*	β	*SE*	*t*	β	*SE*	*t*
Intercept	4.46***	0.12	36.01	4.29***	0.17	24.54	4.25***	0.17	24.99
PS	0.49***	0.04	11.34	0.50***	0.05	10.50	0.50***	0.05	10.31
Group	-0.04	0.17	-0.20	0.06	0.25	0.23	-0.03	0.24	-0.12
PS×Group	0.03	0.06	0.48	-0.25***	0.07	-3.50	-0.09	0.07	-1.23
Energetic Arousal Model									
	Pre			**Post1**			**Post2**		
Variable	β	*SE*	*t*	β	*SE*	*t*	β	*SE*	*t*
Intercept	3.57***	0.13	27.45	3.89***	0.13	28.63	3.85***	0.14	26.76
PS	0.19***	0.06	3.20	0.13*	0.06	2.08	0.33***	0.06	5.12
Group	0.21	0.18	1.16	0.18	0.19	0.96	0.36	0.20	1.77
PS×Group	-0.06	0.08	-0.66	-0.00	0.10	-0.03	-0.03	0.09	-0.29

Note. PS = perceived stress; Pre = Baseline; Post1 = first academic exam assessment; Post2 = second academic exam assessment
* $p < .05$. *** $p < .001$

3.5 Discussion

In the present study, we were able to show that a preventive 20-week aerobic exercise intervention can lower emotional stress reactivity to real-life stress. NA did not differ significantly between participants in the AET and control groups during the exams. This was illustrated by the non-significance of group as a predictor in both statistical models during the stressful episodes. However, the MLMs revealed a significant cross-level interaction of group (control versus AET) and PS on the output NA. The interaction was not significant prior to the exercise intervention, which means that stress reactivity did not differ between groups at baseline. In contrast, the interaction was significant during the academic exams after the aerobic exercise intervention. In conditions of higher PS, AET participants rated lower NA and thus had reduced emotional stress reactivity. The significant reduction in stress reactivity was identified at both episodes during the exams (post1 and post2), with a descriptively higher coefficient at post2. Thus, we confirmed our results of the reduced stress reactivity of the AET group at two different assessment times. Our results are consistent with those from recent cross-sectional laboratory studies that found lower decreases in mood among trained compared with untrained men in response to the TSST (Klaperski et al., 2013).

Because research shows that the accumulated effects of enhanced emotional reactivity (enhanced NA) increase the risk for physical and mental disorders (Cacioppo et al., 1998; DeLongis, Folkman, & Lazarus, 1988; Myin-Germeys et al., 2003; van Eck et al., 1998), these results are relevant for prevention because they support the hypothesis that exercise buffers stress-induced health risks (Gerber & Pühse, 2009; Hamer, 2012). Participants in the AET group had lower NA during conditions of high PS, and thus they may benefit in the long term from a lower accumulation of NA in response to daily life stress. As a consequence, exercise appears to be a promising prevention strategy for reducing accumulated enhanced emotional reactivity to the considerable stresses in real life. Clinical psychology treatments aim to reduce the effects of stressors that are already present. Exercise training serves as a strategy to influence the effects of stressors before they occur (Salmon, 2001). In addition, exercise is a popular, easily accessible low-cost application for reducing NA and a successful add-on to psychological treatments.

Our secondary analyses revealed that the interaction of PS and group did not show a persistent pattern in predicting the different mood dimensions valence, calmness and energetic arousal. The results for the valence dimension (marginally significant at post1 and significant at post2) indicated improved emotional reactivity. Whereas the valence of mood was more positive in the AET group, the results showed a more complex picture for calmness and energetic arousal. An interesting finding was that the reactivity of the calmness dimension was only evident at post1. The non-significant interaction of group×PS at post2 raises the question of whether exercise's effects on calmness decrease over periods of prolonged stress. More research is needed to explain the interplay of stress and exercise regarding the mood dimensions valence, energetic arousal and calmness, for example, to explain the higher energetic arousal of the AET participants observed during the academic examinations.

In the present study, we were able to improve the aerobic capacity of previously inactive students after a 20-week AET by 8.7% on average, with high intra-individual variability (*SD* 12%). De Geus and Stubbe (2007) stated that the average improvement in VO_2max in long-term training studies was approximately 14% after four months of training. Research shows that VO_2max improvement in response to aerobic exercise training differs greatly (by 0–40%) depending on target group, baseline vagal tone, age, gender, training load and genetic disposition (Hautala et al., 2009). Although the present study showed VO_2max improvements lower than the 14% change, the results are statistically significant. Furthermore, the AET group showed significantly reduced emotional stress reactivity compared with the CG.

Based on the present results, people may profit from regular exercise, especially when PS is higher. Interestingly, people do not use exercise during stressful times but prefer to spend more time in suboptimal low-effort activities such as watching television (Sonnentag & Jelden, 2009). There needs to be further examination of the effects on long-term health of exercising compared with low-effort activities during real-life stress.

We do not know exactly which factors contributed to the reduced emotional reactivity to real-life stress among participants who attended the 20-week AET. Earlier studies have argued that it is not the effects of regular exercise adaptations but potentially the aggregated positive effects of acute exercise on mood, reduced tension and elevated beta-endorphins that lead to reduced stress (Reed & Buck, 2009; Salmon, 2001). The results of the present study suggest that people profit not only from general mood enhancement but also from lower

NA, especially in situations of higher demand. Salmon (2001) stated that the particular value of exercise might be its controllability. Although repeated exposure to uncontrollable stressors may also lead to adaptations, they can be achieved much more quickly through controllable stressors (Maier & Seligman, 1976). The present study operationalized acute stress appraisal through perceived control. Participants in the experimental group may have had lower emotional stress reactivity because they perceived more control even in situations of severe stress. Therefore, one explanation for the emotional benefit of regular exercise would be the adaptations to exercise as the repeated but controllable stressor. The potential of regular exercise to reduce stress reactivity and increase self-control was investigated in an intervention study by Oaten and Cheng (2005). Exercisers showed significant improvement in self-regulatory capacity, decreased PS and emotional distress, and enhanced health behaviors compared with the CG. Interestingly, in an additional study with a non-exercise intervention to increase self-control in preparation for upcoming exams, the authors reported increased physical activity in the experimental group who participated in a self-control programme (Megan Oaten & Cheng, 2006).

Although our study revealed interesting findings regarding the effect of aerobic exercise on emotional stress reactivity in real life, some critical aspects have to be discussed. First, the results of the present study are not representative because we used a sample of young, healthy students with rather low levels of NA and mild levels of PS. Participants enrolled in the study voluntarily, and thus students with severe stress may not have participated. However, as we learned from previous studies that analysed exercise-mood associations, lower baseline values indicated higher effects (Reed & Buck, 2009) and high baseline levels may lead to ceiling effects (Gauvin et al., 1996). However, we found significant results, and thus we are optimistic that the effects may be reproducible in a more representative sample.

Second, although we asked participants to rate PS repeatedly throughout the day, we very likely missed some severely stressful moments. Therefore, using a combined protocol (integrating event-based and time-based sampling strategies as well as physiology-triggered assessments) may be an even more suitable method for future studies (Shiffman, 2007) because PS ratings can thereby be initialized during situations of higher stress.

Finally, there are variables we did not control for that could also have influenced NA and PS; context information such as social contacts, activities and location as well as social support and personality are a few of these variables. Future studies should analyse how these variables counteract or moderate the effects of exercise on emotional reactivity during real-life stress.

Conclusion

The present study revealed relevant results that suggest that exercise is an effective prevention strategy for buffering against stress-induced negative health effects. In addition, we depicted how Ambulatory Assessment benefits research on the stress-exercise association. Even during the examination period, some participants perceived very low levels of stress and at other times, different students experienced more or less stress, indicating inter- and intra-individual variability. Negative affect values were on average above the mean of the NA scale, and thus, the averaged pre-/post- single assessments such as were used in earlier studies, would not have yielded the present findings. The situation-specific and repeated assessments of the interactions between the predictor group and PS and the dependent variable NA allowed us to detect more complex results.

We used two assessment episodes during the exams and were able to confirm the results for both points in time. Thus, we could strengthen our results by confirming the results at two different times and to illustrate increased representativeness. The present study showed that it is worth analysing intra- and inter-individual effects when analysing intervention effects. Future studies should investigate in more detail how individuals at different fitness levels react in situations of different stress severity and contexts and how the impacts of acute and regular exercise interact regarding emotional reactivity to stress in real life. Furthermore, it will be interesting to identify the factors that are responsible for successfully reducing emotional stress reactivity through aerobic exercise. Therefore, more studies that use Ambulatory Assessment to evaluate the effects of regular exercise on both physiological and emotional stress reactivity are needed. In addition, continuously monitoring physical activity can capture the influences of the circular associations between physical activity and stress in real-life settings (Bussmann et al., 2009).

4 Regular exercise and physiological stress reactivity

Published as

Von Haaren, B., Ottenbacher, J., Muenz, J., Neumann, R., Boes, K., & Ebner-Priemer, U. W. (under Review). Does a 20-week aerobic exercise training increase our capabilities to buffer real-life stressors? A randomized, controlled trial using Ambulatory Assessment. *European Journal of Applied Physiology*.

4.1 Abstract

Purpose: The cross-stressor adaptation hypothesis suggests, that regular exercise leads not only to decreased physiological stress responses to physiological stressors, but also to decreased physiological responses to psychological stressors. Even though such an intervention to buffer psychological stressors might be of utmost importance, empirical evidence is mixed. This may be explained by the use of cross-sectional designs and non-personally relevant stressors. Using a longitudinal design, we hypothesized that a 20-week aerobic exercise training (AET) does reduce physiological stress responses to psychological real-life stressors in sedentary students.

Methods: Sixty-one students were randomized to either a control (CG) or an AET group. The academic examination period (end of the semester) served as a real-life stressor. We used ambulatory assessment methods to assess heart rate variability (LF/HF, RMSSD), physical activity and perceived, subjective stress during two days of everyday life and multilevel models for data analyses. Aerobic capacity (VO_2max) was assessed pre- and post-intervention via cardiopulmonary exercise testing to control for the effectiveness of the intervention.

Results: As hypothesized, the AET group showed significantly reduced LF/HF (β = -0.15, t = -2.59, p = .011) and increased RMSSD (β = 0.15, t = 2.34, p = .021) to real-life stress compared to the CG.

Conclusions: Using a longitudinal design and real-life stressors, we could show that exercise appears to be a useful preventive strategy to buffer the deleterious effects of stress on the autonomic nervous system.

4.2 Introduction

Mental stress is an increasingly prominent ailment in industrialized countries, and it represents a prominent health risk factor, nearly as detrimental as smoking or diabetes (Yusuf et al., 2004). Accordingly, interventions to better cope or buffer stressful experiences are of major importance. The cross-stressor adaptation hypothesis suggests, that regular exercise leads not only to decreased physiological stress responses to physiological stressors (i.e. improved adaptation), but also to decreased physiological responses to psychological stressors

(Sothmann, 2006; Sothmann et al., 1996). Over the recent decades, numerous studies empirically investigated the cross-stressor adaptation hypothesis, mostly by comparing the physiological reactivity of physically fit versus unfit people to mental stress tasks (Albright et al., 1992; Calvo et al., 1996; Childs & de Wit, 2014; de Geus et al., 1993; Jackson & Dishman, 2006; Klaperski et al., 2013; Rimmele et al., 2007, 2009; Spalding et al., 2000).

Unfortunately, reviews and meta-analyses revealed inconsistent results in these previous studies (de Geus et al., 1993; Forcier et al., 2006; Gerber & Pühse, 2009; Jackson & Dishman, 2006; Sothmann et al., 1991). While two meta-analyses found evidence for diminished physiological stress reactivity to psychological stressors in physically fit and exercising individuals (Crews & Landers, 1987; Forcier et al., 2006), another meta-analysis (Jackson & Dishman, 2006) did not indicate empirical support for reduced reactivity. Specifically, Forcier et al. (2006) reported decreased physiological reactivity, heart rate (HR) and systolic blood pressure to psychological stressors in physically fit versus unfit individuals including cross-sectional and longitudinal studies. In contrast, Jackson and Dishman, (2006) did not present any support for reduced physiological stress reactivity, but empirical evidence for improved physiological recovery after psychological stress. In almost the same manner, the results of previous randomized, controlled trials are inconsistent. While some studies found decreased physiological stress reactivity (Holmes & Roth, 1988; Klaperski et al., 2014; Spalding et al., 2004), others did not demonstrate differences in physiological stress reactivity between control and experimental groups (Albright et al., 1992; de Geus et al., 1993; Lindgren et al., 2013; Sloan et al., 2011).

In our opinion, two main issues related to study design are responsible for the aforementioned discrepancies in previous studies. First, even though the cross-stressor adaptation hypothesis has been described as a within-subject hypothesis with a clear temporal order (physical exercise does reduce the physiological stress reactivity to psychological stressors over time within given subjects), most studies use between-subject designs. I.e. they do not investigate subjects over time, but out of convenience, compare physically fit and unfit participants in a cross-sectional manner. However, to properly test the cross-stressor adaptation hypothesis a within-subject design with intervention is necessary.

Second, the majority of previous studies used artificial stressors in a laboratory environment. While laboratory studies deliver important insights under controlled conditions, several authors have argued that studies conducted in the laboratory may reveal effects with smaller size or the outcomes may not be comparable to laboratory findings at all, principally due to the non-personally relevant stressors and the artificial setting (Gauvin et al., 1996; Schwartz, 2003; Sloan et al., 2011; H. Wilhelm et al., 2012; Zanstra & Johnston, 2011). To improve ecological validity, physiological processes, physical activity and self-reported psychological variables (e.g. perceived stress) can be assessed in real life using ambulatory assessment (Trull & Ebner-Priemer, 2013). The few real-life studies on the cross-stressor hypothesis did demonstrate encouraging results. Specifically, Ritvanen, Louhevaara, Helin, Halonen, and Hänninen (2007) showed that aerobic fitness was associated with reduced HR and perceived stress during work in teachers. Brooke and Long (1987) found maintained lower HR levels in fit compared to unfit subjects during rappelling. Finally, men with higher VO_2max showed lower HR in response to a “guerilla slide”, a stressful military real-life task (Wittels et al., 1994). However, the few studies examining the stress-exercise association with real-life stressors were all cross-sectional.

Despite the encouraging results of previous cross-sectional studies, they do not allow us to draw causal conclusions. It still remains unclear whether regular exercise leads to lower physiological stress responses to psychological stressors, or whether people with a favorable psychological profile tend to exercise more (de Geus & Stubbe, 2007). To our best knowledge, no study investigated the effects of exercise on physiological stress responses using a randomized, controlled trial, ambulatory measures and a real-life psychological stressor.

To test the cross-stressor hypothesis longitudinally with real-life stressors, we conducted a randomized, controlled trial. We hypothesized that after participating in a 20-week aerobic exercise training (AET), students would exhibit lower physiological stress response during real-life psychological stressors compared to a control group. We used the academic examination period (end of the semester) as real-life stressor, because examinations have been shown to induce noticeable stress in students (Hazlett et al., 1997; Spangler, 1997) accompanied with significantly elevated cardiovascular reactivity (Sausen et al., 1992; Zanstra & Johnston, 2011; Hazlett et al., 1997). Physiological stress response was operationalized by continuous measures of heart rate variability (HRV) in every-day life using ambulatory assessment (Trull & Ebner-Priemer, 2013).

4.3 Methods

4.3.1 Participants

Sixty-one male inactive (≤ 1x moderately active for 60 min/week) electrical engineering students (M_{age} = 21.4 ± 1.8) were recruited during first week lectures of the semester. The sample resulted from two phases (each including 30 participants) lasting for one semester (October 2011 to March 2012 and October 2012 to March 2013). To control for differences between exam periods, subjects had to be in the 3rd or 5th[2] semester of their studies. Interested persons were contacted via email to receive an invitation to the study kick-off meeting. All participants were given detailed information about the study and willing participants gave written consent. Students did not receive financial compensation, but did receive credit points within their course if they completed all measurements and the intervention (experimental group).

4.3.2 Procedure

Participants were randomized to either a wait list control (CG) or an AET group, stratified by their habitual physical activity level assessed via questionnaire (Jekauc et al., 2013). To test the effects of the AET intervention on real-life stress, we used two specific real-life assessment periods (Figure 4.1). We set the pre-intervention baseline assessment to the beginning of the semester because we assumed that it represents a regular academic period where students experienced low stress (Loft et al., 2007). The post-intervention assessment

2 In Germany, Bachelor studies consist of six semesters with a duration of 4 months each. Semesters start in October and April.

was set to a real-life stressful episode, an academic examination (Figure 4.1). Ambulatory ECG, physical activity and perceived stress were assessed pre- and post-intervention for a two-day period. To obtain valid data during academic examinations every participant completed two separate assessment periods during academic examinations (Post1 and Post2; two days each). The time span between the exam and the end of data recording was restricted to at least one and a maximum of two days.

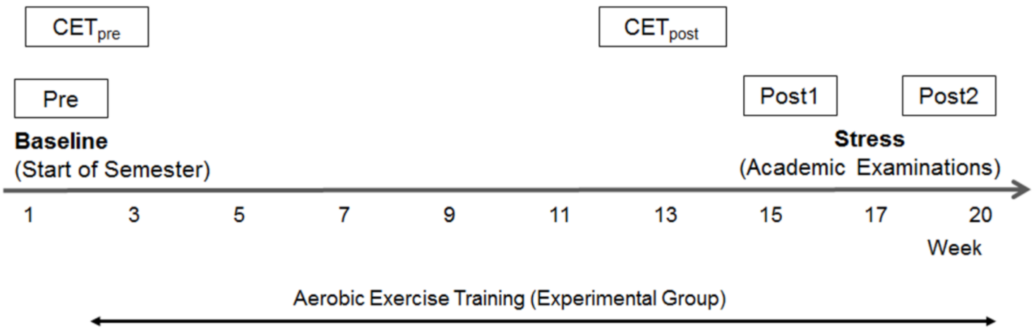

Figure 4.1: Illustration of the study design: Timeline with pre- and post- assessments of physiological measures, cardiopulmonary exercise testing (CET) and the duration of the exercise intervention

As a manipulation check of the AET intervention, we assessed aerobic capacity pre- and post-intervention. We conducted a cardiopulmonary exercise pre-test (CET_{pre}) during the first two weeks of the study (start of semester), prior to the intervention of the AET group. After completion of the pre-tests (November 1st), the aerobic exercise training for the AET group started. After 3.5 months of AET (see Figure 4.1), we conducted the cardiopulmonary exercise post-test (CET_{post}) with exactly the same procedure as the pre-tests. Participants completed the post-tests prior to the examination period to avoid any influence on performance. The wait list CG received AET after the end of the study.

4.3.3 Measures

For the acquisition of objective data the ECG- and activity monitor ecgMove (movisens GmbH, Karlsruhe Germany) was used. Participants received the devices one day before the assessments started. The start time was programmed to 10 a.m. and the measurement ended on the next day at 10 p.m., thus recording 36 hours including one night. Participants had to complete an assessment protocol addressing times during which the device was not worn and corresponding physical activity, special incidents, and consumption of caffeine, alcohol and cigarettes.

Participants wore the ecgMove at the chest with a textile dry electrode chest belt. ecgMove is able to record a 1-channel ECG (1024 Hz), 3-axis acceleration (64 Hz) and barometric altitude (8 Hz) as raw data on internal memory. Raw data was able to be read out via USB. Data processing was done using DataAnalyzer 1.7 (movisens GmbH). The following steps were performed internally in DataAnalyzer:

HR/HRV

Activities of daily living are characterized by permanent movement-induced noise. Artifacts were detected by looking for non-physiological ECG signal sections in terms of QRS amplitudes as well as the number of zero crossings. Artifact regions were marked as such and excluded from further processing. After detecting R-peaks (P. Hamilton, 2002) in the ECG waveform according to published guidelines , RR-intervals were calculated. To obtain only normal to normal (NN) intervals, filtering of RR intervals was performed by checking for non-physiological changes in consecutive RR as well as changes in the R amplitude (Clifford, McSharry, & Tarassenko, 2002). HR was calculated from the valid NN intervals. From the filtered intervals segments with a length of 120s and a shift of 30s were built. Segments with a cumulated NN interval time smaller than 90% of the segment length were dismissed.

HRV can be measured through time domain and frequency domain analyses. From popular time domain indices, we decided to calculate the root mean square of successive differences (RMSSD), a short term component of HRV and reflecting predominantly vagally mediated autonomic alterations (Task Force, 1996). In addition, we calculated the LF/HF ratio which is suggested to display the sympathovagal balance (Malliani, Pagani, Montano, & Mela, 1998). While the low-frequency (LF) component (0.04-0.15 Hz) is modulated by both parasympathetic and sympathetic nervous system, the high-frequency component (0.151-0.40 Hz) is defined as a predominantly parasympathetic marker and the interpretation of VLF is unclear. RMSSD (ms) was calculated for each segment (Task Force, 1996). All segments were detrended to prepare them for spectral analysis (Eleuteri, Fisher, Groves, & Dewhurst, 2012). Detrended segments were interpolated at 4 Hz, and the fast Fourier transform (FFT) was then calculated for each segment. Spectral power was calculated for LF (0.04–0.15 Hz) and HF (0.15–0.4 Hz) regions respectively to calculate LF/HF ratio (Task Force, 1996). We used 1 min as output rate for HR and all HRV parameters.

Physical activity

Acceleration and barometric signals were used for physical activity estimation. The raw acceleration signal was at first high pass filtered in each axis to remove the gravitational DC component. Then a low pass filter was applied to filter non body movement accelerations (Van Someren, Lazeron, Vonk, Mirmiran, & Swaab, 1996). Then the three axes were combined by calculating the vector magnitude. The parameter movement acceleration intensity (in [g]) was calculated for each minute by averaging the vector magnitude signal.

Activity recognition was then performed by calculating various features from the acceleration and barometric signals. Activities were classified from the extracted features (lying, inactivity, walking, jogging, stairs). For each activity a regression model for activity energy expenditure was selected. Activity energy expenditure was calculated using the following model parameters movement acceleration, altitude change, age, gender, weight and height. Activity energy expenditure was calculated for each minute by averaging (Anastasopoulou et al., 2014, 2012). Using the acceleration data sleep/wake classification was performed based on the algorithm of Cole, Kripke, Gruen, Mullaney, and Gillin (1992).

Aerobic capacity

Maximum oxygen consumption (VO_2max) is the primary parameter for determining aerobic capacity. An effective AET intervention (significantly enhanced VO_2max) was presumed for the hypothesized effects of the intervention on real-life stress. Thus, as a manipulation check to assess the aerobic capacity, VO_2max_{rel} (ml/min/kg) was determined via cardiopulmonary exercise testing (MetaMax 3B, cortex-biophysik) on a treadmill until exhaustion, with an initial pace of 6 km/h, a continuous slope of 1% and an increase of 2 km/h per stage every three min (Dickhuth, Mayer, Röcker & Berg, 2007). HR was recorded continuously using POLAR HR monitors (RS800). Within a standardized interruption of 20 seconds between stages, an arterial blood sample was taken from the participants' hyperaemic earlobe into a 20µl end-to-end capillary for the analysis of blood lactate. All participants achieved a Respiratory Exchange Ratio (RER[3]) of ≥ 1.1, a HR of at least 220 beats minus age (T. Meyer & Kindermann, 1999) and were appraised as exhausted by an experienced instructor. Thus for all participants an achievement of VO_2max was assumed.

Perceived stress

To assess perceived stress, we used electronic diaries (Touch Diamond 2 ,HTC Germany GmbH, Frankfurt, Germany) and the software MyExperience movisens Edition (movisens GmbH, Karlsruhe, Germany) to install the scales on the diaries and to program time stamps and intervals between diary prompts. Participants answered the following question presented on the diary screen by choosing the appropriate number on the presented scale (based on stress - rating scales of previous studies; e.g., (Åkerstedt, Kecklund, & Axelsson, 2007) using the integrated diary touch pen: "How much stress did you experience during the last two hours?" (0 = *no stress at all* to 7 = *extreme stress*). All diary prompts were initialized automatically by a vibrating signal every two hours with a varying incidence of the signal of one to five min to prevent participants from waiting for the signal. All diary prompts occurred between 10 a.m. and 10 p.m. If participants missed a signal, reminders were sent after 5, 10, and 15 min.

4.3.4 Intervention

Participants of the experimental group attended a 20-week aerobic exercise training (AET) until they had completed both measurements during the academic examinations. Besides VO_2max, the main outcomes of the cardiopulmonary exercise test were maximum running speed, lactate threshold, and individual anaerobic threshold. Based on these, we calculated individual HR zones for each participant (zone I: aerobic; zone II: aerobic–anaerobic) using the software

3 RER: ratio between the amount of carbon dioxide produced (VCO_2) and the oxygen consumed (VO_2) during one breath.

Ergonizer® (Sports medicine, Freiburg, K. Röcker) and installed the training schedules and the HR target zones on the RS800 HR monitors. Skilled exercise science students supervised and instructed the running groups of 7–8 people by adhering to a standardized training schedule for AET (Roecker, 2007). At the beginning, running sessions lasted about 30 min and included walking phases of 2 min. Besides a continuous increase in duration of training (3 min/week) over time, intensity was progressively increased by adding intervals of 3 and 4 min in zone II after week 4. Participants completed the training in the group and wore the HR monitors to record the training and meet their individual HR requirements. To allow for individual but group-based running sessions, the training sessions took place outdoors in an area close to the campus with fixed trails. Training sessions were conducted during lunch time to allow for short routes and little time loss. Students had to complete two training sessions every week.

4.3.5 Data Analysis

We used Multilevel Models (MLM) to calculate the effects of the exercise intervention on HRV during real-life stress. By using MLM, we were able to provide consideration to our hierarchical data structure of multiple observations of HR, HRV and physical activity within participants. Furthermore, we were able to include participants with missing data, estimate within-subject effects as well as between-subject effects and handle uneven numbers of observations per participant (Hoffman & Rovine, 2007). In addition, we were able to control for physical activity continuously. We calculated separate day- and night-specific models for the HRV parameters as dependent variables. To calculate MLM based on aggregated mean values per hour, we considered only hours with more than 30 min of valid data and participants with at least 18 hours of valid data (> 30 min/hour). Due to their skewed distribution, we log transformed all HRV and physical activity variables.

Day-specific analyses

The day-specific analyses were based on both days (10 a.m. to 10 p.m.) of the second period of examination measurements because it took place during the middle of the examination period (Post2). To control for physical activity, we included the sum of activity intensity (mean/hour based on movement acceleration) in the model. In addition, we included baseline HRV (Pre; mean over two days at baseline) as a predictor. To consider differences between the two days of measurement, we calculated a three-level model including a random intercept between days. Time was coded as 0 for the first hour during the day (10 a. m.) and as 11 for the last hour during the day (9 p.m.).

Night-specific analyses

For the night-specific analyses, we used data from the two nights of both measurements during academic examinations (Post1 and Post2). Within the time span of 10 p.m. and 10 a.m. (next morning), all data that indicated sleep (accelerometer-based sleep/wake detection; see methods section) were analyzed. In the statistical model, we added group as fixed effect. To control for physical activity of the previous day on nightly HRV values, activity energy expenditure of the past day (AEEpastday) was included in the model. In addition, we included baseline HRV (Pre; mean HRV for the night at baseline) as a predictor. Time was coded as 0 for the first hour during the night (10 p.m.) and as 11 for the last hour during the night (9 a.m.).

Furthermore, we included the perceived stress level (grand-mean centered) of students as a predictor in day- and night-specific models because the impact of perceived stress on physiological stress response can differ between individuals (N. Y. Weekes et al., 2008; N. Weekes et al., 2006). For the day-specific analysis we added VO_2max_{rel} pre- intervention (VO_2max_{rel}_pre) in the model to analyze whether the initial VO_2max_{rel} value was associated with higher HRV during the day. For the night-specific analysis, we added the difference in VO_2max_{rel} from pre- to post-intervention (VO_2max_{rel}_Diff) to analyze whether a higher improvement in VO_2max_{rel} predicted HRV. Both variables were grand-mean-centered. Level 1 variables (observations) were movement acceleration/per hour; Level 2 (days) variables were perceived stress and Level 3 (person) included baseline HRV, group, and VO_2max_{rel}_pre. Note that the night-specific model was the same except that physical activity was controlled with a Level 2 instead of a Level 1 variable (activity energy expenditure aggregated over the past day) and VO_2max_{rel}_Diff was included instead of VO_2max_{rel}_pre.

To determine whether the intervention had successfully improved the AET group's aerobic capacity, we conducted an analysis of covariance (ANCOVA) with post-intervention VO_2max_{rel} as the dependent variable (CET_{post}), pre-intervention VO_2max_{rel} as the covariate (CET_{pre}) and group (CG/AET) as the treatment factor.

4.4 Results

Our final data set indicated good subject compliance. For the day-specific analysis, 3.4% of missing data were due to non-wear times and for the night-specific analysis, it 3% of missing data were due to non-wear times. Further missing data was caused by ECG artifacts (mainly caused by a faulty batch of textile ECG chest straps), with 12.2% of artifacts caused during the day and 8.9% caused during the night. Participants of the AET group and the CG did not differ in person characteristics or cardiopulmonary exercise test parameters prior to the intervention. We excluded six participants from the day-specific analysis because they had more than 50% of missing data per hour. For the night-specific analysis, we removed data of six participants of the first measurement and data of five participants of the second measurement during examinations.

For the day-specific analyses, 1164 observations were available. For the night-specific analysis, 776 observations were available. Intraclass coefficients were $\sigma = .39$ for HR, $\sigma = .78$ for LF/HF and $\sigma = .77$ for RMSSD, indicating that intra-individual variation caused 61%, 22% and 23% of the variance, respectively.

4.4.1 Descriptive statistics

Mean values of HR and LF/HF were similar in both groups during the night at baseline but the AET group had a descriptively higher baseline level of RMSSD during the night. In contrast, baseline RMSSD during the day was similar between both groups, as well as mean LF/HF ratio and mean HR values (Table 3.1). Average group values of the night did not illustrate changes from baseline to academic examinations in all HRV parameters. However, during the two days of academic examinations, the AET group showed on average reduced HR (9.3%) and increased RMSSD values (25.9%) compared to baseline (Table

3.1). During the examination period, the AET showed 42% higher mean RMSSD compared to the CG at day 1 and 30.6% higher mean RMSSD during day two.

Table 3.1: Descriptive statistics (*M, SD, Min and Max*) of the HRV parameters for the night and day during baseline and examinations

Night						
	AET[a]			**CG**[b]		
Variables	*M (SD)*	*Min*	*Max*	*M (SD)*	*Min*	*Max*
Baseline						
HR (b/min)	57.76 (6.2)	46.86	78.72	60.11 (8.7)	46.29	81.43
RMSSD (ms)	71.44 (30.2)	15.04	121.88	56.64 (23.9)	13.66	121.47
LF/HF	1.94 (1.3)	0.55	6.36	1.88 (0.9)	0.70	3.85
AEE_pastday	999.42 (312.9)	461.37	1777.88	1070.78 (353.12)	640.16	2428.98
Exam						
HR (b/min)	55.48 (7.4)	41.32	79.64	58.3 (6.5)	42.82	89.84
RMSSD (ms)	73.14 (34.96)	11.03	214.40	54.54 (24.4)	9.40	170
LF/HF	1.87 (1.3)	0.23	11.14	1.81 (0.89)	0.30	6.81
Day						
	AET[c]			**CG**[d]		
Variables	*M (SD)*	*Min*	*Max*	*M (SD)*	*Min*	*Max*
Baseline						
HR (b/min)	83.55 (7.8)	70.51	111.60	82.65 (8.6)	68.51	97.30
RMSSD (ms)	42.65 (20.8)	16.21	129.40	37.41 (14.8))	23.57	86.63
LF/HF	4.16 (1.9)	0.73	8.56	4.16 (1.3)	1.99	6.67
Exam						
PA (mg)	2947 (2417)	331.00	38367	2922 (2169)	411.00	14405
HR (b/min)	76.48 (12.9)	49.64	144.29	80.91 (12.9)	46.86	125.51
RMSSD (ms)	52.38 (32.3)	6.70	186.83	38.34 (18.3)	7.53	153.73
LF/HF	3.51 (2.2)	0.41	15.88	3.70 (1.7)	0.74	11.62

Note. All HRV measures are log transformed values; HR = Heart Rate (beats/minute); PA = physical activity (sum of acceleration per hour in [g]); Baseline LF/HF, RMSSD and HR are aggregated mean values over the two days during baseline (day) and over the night (night); AEE_pastday = Activity energy expenditure during the first day of examination measurement.
[a] *n* = 28. [b] *n* = 24. [c] *n* = 30. [d] *n* = 25.

4.4.2 Day-specific effects of AET on HRV

RMSSD

As hypothesized, the AET group showed significantly higher ($\beta = 0.15$) RMSSD during the examination period compared to the CG (Figure 4.2) when controlling for activity, baseline RMSSD and perceived stress and VO_2max_{rel}_pre. Higher hourly activity levels as well as higher perceived stress (per day) lead to decreased RMSSD, whereas a higher RMSSD at the beginning of the semester predicted a higher RMSSD during the examinations (Table 3.2). Neither the Group$\times VO_2max_{rel}$ interaction nor the VO_2max_{rel} explained noticeable variance.

As CG was coded as 0 and the AET group was coded as 1, the model parameter estimates presented in Table 3.2 have the following interpretation (exemplary for RMSSD): (1) the intercept is the level of RMSSD (Ln) of the CG during the academic examinations, (2) the group estimate is the difference in RMSSD (treatment minus control), (3) the baseline estimate is the change in RMSSD with the level of baseline RMSSD in the control group, (4) is the change in RMSSD with the level of VO_2max_{rel} pre-intervention, (5) the Group $\times$ VO_2max_{rel} estimate is the difference in RMSSD between the control and AET group in dependence of the VO_2max_{rel} level pre- intervention. The random effects between-persons and -days illustrated that RMSSD differed between the two days of measurement and between persons. The significant estimate for autocorrelation indicates that RMSSD observations that were closer in time were more similar than more distant observations.

Table 3.2: Parameter estimates for multilevel models of LF/HF and RMSSD for the day

	RMSSD			**LF/HF**		
Fixed effects	β	*SE*	*t*	β	*SE*	*t*
Intercept	4.37***	0.15	28.92	-1.27***	0.15	-8.77
Group	0.15*	0.07	2.34	-0.15*	0.06	-2.59
Baseline HRV	0.01***	0.00	8.23	0.25	0.02	11.99
PA	-0.18***	0.02	-10.99	0.19***	0.01	13.14
VO2maxrel_pre	0.01	0.00	1.69	-0.01	0.01	-0.93
VO2maxrel_pre*Group	-0.02	0.00	-1.80	0.00	0.01	0.33
Perceived Stress	-0.06**	0.02	-2.65	0.04	0.02	1.7
Random effects	β	*SE*	*z*	β	*SE*	*z*
Intercept (ID*Day)	0.78**	0.25	3.12	0.07***	0.01	5.31
Activity	-0.08**	0.03	-2.87			
Intercept and Activity	0.01**	0.00	2.79			
Residual	0.07***	0.01	4.25	0.10***	0.01	15.57
Autocorrelation	0.64***	0.04	15.97	0.44***	0.04	12.23

Note. N = 55; VO_2max_{rel}_pre = VO_2max_{rel} pre-intervention; Baseline HRV = mean HRV aggregated over day at baseline; PA = physical activity (sum of activity intensity in milli-g per hour). Group is coded 0 for the CG and 1 for the AET Group
p* < .05; *p* < .01, *** *p* < .001

LF/HF

In accordance with the results for RMSSD, the AET group showed significantly reduced LF/HF during the examination period (Table 3.2; Figure 4.2) when controlling for activity, baseline LF/HF and perceived stress. A higher baseline level of LF/HF predicted higher LF/HF during the examinations. Furthermore, higher activity predicted higher LF/HF (Table 3.2). In contrast to the results for RMSSD, perceived stress did not predict LF/HF.

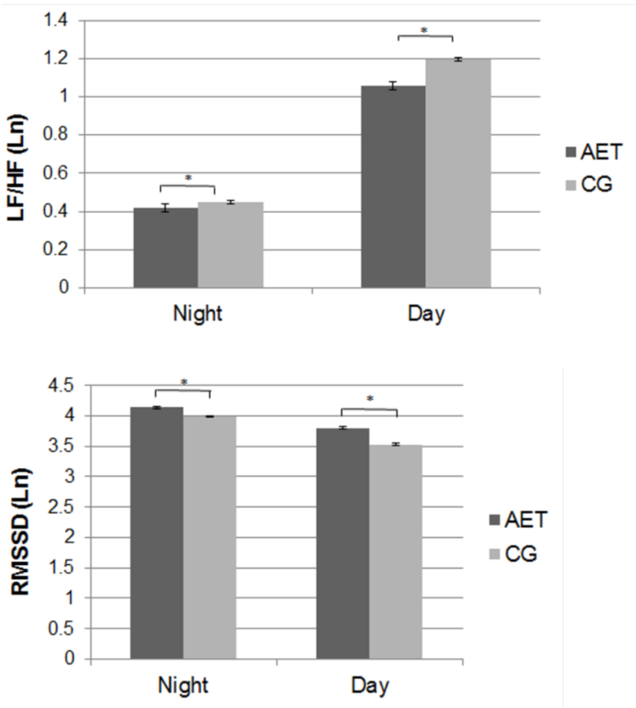

Figure 4.2: LF/HF and RMSSD (predicted values) during the day and night at baseline and during examinations.

HR

The AET group showed significantly reduced HR during the examination period compared to the control group (β = -0.06; t = -3.69; p < .001) when controlling for activity, baseline and perceived stress. As expected, a higher activity level significantly predicted a higher HR during the examinations (β = -0.01; t = 6.50; p < .001). In addition, participants with a higher baseline HR had significantly higher HR during the examination period. More importantly, higher perceived stress predicted a significantly higher examination HR (β = -0.02; t = 3.01; p = .003). In addition, the $VO_2max_{rel_}$pre (β = -0.01; t = -2.82; p = .006) and the group×$VO_2max_{rel\_}$ pre interaction (β = 0.01; t = 2.74; p = .007) significantly predicted HR during examinations. Participants with a higher baseline VO_2max_{rel} level showed reduced HR during the examinations. In the CG, the lower the $VO_2max_{rel_}$pre was, the higher the heart rate was during examinations. In contrast, within the AET group, participants had similar levels of heart rate irrespective of different $VO_2max_{rel_}$pre. The between-person and -days random effects revealed that the HR and the effect of the activity level varied significantly between persons and the two days of measurement (Table 3.2).

4.4.3 Night-specific effects of AET on HRV

RMSSD

As hypothesized, the AET group showed significantly increased RMSSD values compared to the CG when controlling for activity and perceived stress of the past day, baseline RMSSD and VO_2max_{rel}_Diff. Participants with higher RMSSD at baseline had higher RMSSD during examinations and (Table 3.3). While VO_2max_{rel}_Diff significantly predicted RMSSD at night during academic examinations, perceived stress and PA of the previous day did not.

LF/HF

Participants of the AET group showed reduced LF/HF compared to the CG (Table 3.3). Furthermore, participants with a higher LF/HF ratio during baseline showed higher values during the examination period and the difference in VO_2max_{rel} significantly predicted LF/HF ratio. In accordance with the results for RMSSD, the activity level of the past day and the stress level did not predict LF/HF. Note that because of the frequent studying by students during academic examinations, the activity level was very low in both groups during the two days before the examination (Table 3.2). LF/HF and the effect of the baseline LF/HF varied between-persons and -nights (Table 3.3).

Table 3.3: Parameter estimates for multilevel models of LF/HF and RMSSD for the night

	RMSSD			LF/HF		
Fixed effects	β	*SE*	*t*	β	*SE*	*t*
Intercept	3.95***	0.07	53.28	0.78***	0.07	10.92
Group	0.25*	0.12	2.08	-0.39***	0.11	-3.62
Baseline HRV	0.01***	0.00	5.30	0.47***	0.06	7.47
AEE_Pastday	-0.00	0.00	-1.82	-0.00	0.00	-0.29
VO2maxrel_Diff	-0.03*	0.01	-2.39	0.04***	0.01	3.92
Perceived Stress	-0.03	0.03	-1.13	0.02	0.02	1.02
Random effects	β	*SE*	*z*	β	*SE*	*z*
Intercept	0.06	0.04	1.60	0.07***	0.01	5.37
Residual	0.14***	0.04	3.56	0.10***	0.01	15.2
Autocorrelation	0.84***	0.05	18.23	0.45***	0.04	12.3

Note. *N* = 50; $VO2max_{rel}$_Diff = Difference in VO_2max_{rel} between pre- and post-intervention; Baseline HRV = mean Baseline level; AEE_Pastday = Activity energy expenditure during the past day.
Group is coded 0 for the CG and 1 for the AET Group
p* < .05; *p* < .01, *** *p* < .001

HR

The night-specific analyses of HR did not show the same distinct group influence compared to the day-specific analysis. Participants of the AET Group showed reduced HR (β = -0.04, $t = -1.96$, $p = .053$) during the examination period compared to their control counterparts. In contrast to RMSSD and LF/HF, the activity level of the past day significantly predicted the HR values during the examination period. Participants, who were more active during the day had higher HR during the night (β = 0.00; $t = 2.20$; $p = .030$). Furthermore, participants with higher HR at baseline had higher HR during the examination period (β = 0.00; $t = 3.59$; $p < .001$).

Aerobic Capacity

Aerobic capacity operationalized via VO_2max_{rel} increased by 8.8% (pre: 48.5 ± 6.5; post: 52.8 ± 6.4) in the AET group and decreased by 5.1% (pre: 50.2 ± 6.5; post: 47.6 ± 6.8) in the CG. The ANCOVA revealed significance for the factor "group" in $VO_2max_{rel,}$ $F(1, 56) = 55.3$; $p < .001$; $\eta2 = .51$ indicating a strong effect (J. Cohen, 1988) of the intervention.

4.5 Discussion

As hypothesized, the aerobic exercise intervention lead to reduced physiological responses during real-life stress, supporting the cross-stressor adaptation hypothesis. Specifically, participants of the AET group exhibited higher HRV (lower LF/HF and higher RMSSD) during the real-life stress examination period compared to the CG. Thus, our findings fully support the cross-stressor adaptation hypothesis, which suggests that regular exercise can lead to decreased physiological stress responses to psychological stressors. However, our findings are partially in contrast to previous meta-analyses and reviews pertaining to the cross-stressor adaptation hypothesis, which have demonstrated inconsistent results. While two meta-analyses reported support for the cross-stressor adaptation hypothesis (Crews & Landers, 1987; Forcier et al., 2006), another did not demonstrate any support for reduced stress reactivity, but it indicated faster recovery after stress (Jackson & Dishman, 2006). We suppose that two methodological issues may have caused our favorable results: First, we used a personally-relevant real-life stressor – an academic examination. Second, we were able to investigate within-subject associations as we used an intervention design. Both issues might increase the detectable effect size of the cross-stressor adaptation hypothesis. Our results are in line with the recent findings of Klaperski et al. (2014) which used a more naturalistic laboratory stress task as well as a within-subject intervention design. They reported reduced HRV reactivity in response to the Trier Social Stress Test (TSST) after 12 weeks of exercise training in healthy men. Our findings provide some evidence regarding the involved physiological processes. RMSSD has been shown to be a very good marker of vagal tone in ambulatory ECG studies (Goedhart, Van Der Sluis, Houtveen, Willemsen, & De Geus, 2007). Thus, the significantly higher RMSSD values of the AET compared to the CG observed in our study suggests that AET can buffer the stress-induced deteriorated HRV by improved parasympathetic activity. The utility of the LF/HF ratio as a marker of autonomic balance has been the subject of some controversy (Eckberg, 1997; Malliani et al., 1998).

Unfortunately, we did not assess a parameter which clearly reflects sympathetic activity, such as the pre-ejection period (Cacioppo et al., 1994), however, the significantly lower LF/HF ratio of the AET compared to the CG in the present study provides initial support that reduced sympathetic activity contributes to the buffering effect of AET on stress-induced deteriorated HRV.

We found increased RMSSD and decreased LF/HF (and HR) in the AET group compared to the CG both during the night and the day of an academic examination period. Previous research has shown that real-life stress can impair restorative function of sleep illustrated by decreased HRV (Jackowska, Dockray, Endrighi, Hendrickx, & Steptoe, 2012; Pichot et al., 2002). Specifically, Sakakibara, Kanematsu, Yasuma, and Hayano (2008) used ambulatory pulse wave recording and found decreased HF in university students during the night one day prior to examinations. Regular exercise can induce increased nocturnal HRV (Nummela, Hynynen, Kaikkonen, & Rusko, 2010; Vesterinen et al., 2013), especially through increased parasympathetic activity. Furthermore, regular exercise is associated with improved sleep quality (Youngstedt, 2005). Although we did not assess sleep using sophisticated multichannel EEG in a sleep laboratory, our preliminary findings of significantly higher RMSSD in the AET group during day and night may suggest that exercise also buffers the deleterious effects of stress through improved recovery during the night.

Besides other real-life stressors such as medical internships (Lin et al., 2013), shift work or other job demands (Vrijkotte et al., 2000), academic examinations are a useful real-life stressor because they can induce significantly elevated cardiovascular reactivity (Hazlett et al., 1997; Lucini, Norbiato, Clerici, & Pagani, 2002; Sausen, Lovallo, Pincomb, & Wilson, 1992; Zanstra & Johnston, 2011), have a discrete start and end, as well as natural and frequent occurrence. Furthermore, they permit consistent characteristics of the situation across participants and allow for the assessment of a pre-stress baseline (Hazlett et al., 1997; Zanstra & Johnston, 2011). The descriptively similar baseline and examination values in our study may question whether students experienced noticeable physiological stress during the examination period. Several studies reported comparable values under real-life examination stress in student populations (Lucini, Di Fede, Parati, & Pagani, 2005; Saito, Hiya, Uemura, & Furuta, 2008;

Tharion, Parthasarathy, & Neelakantan, 2009). The comparison of studies examining autonomic changes during academic examination periods is difficult due to a discrepancy in the time points at which measurements were performed (one week before, immediately before, during and after the examination), specific measures obtained and a variety of reported parameters (Hazlett et al., 1997; Lucini et al., 2002; Sakakibara et al., 2008; Spangler, 1997). However, assessing HRV immediately before examinations, Lucini et al (2002) reported lower HRV values.

We assumed that a significant improvement in aerobic fitness in the AET group was required to identify effects on HRV in response to the real-life stressor. We were able to significantly improve VO_2max of the AET group by on average 9% while it decreased in the CG by 5%. Previous studies depicted very heterogeneous results for VO_2max improvement after aerobic exercise training due to influencing factors like target group, baseline vagal tone, age, gender, training load and genetic disposition (Hautala et al., 2009). We also observed these intra-individual differences in VO_2max improvement (SD = 6.4).

This study is not without limitations which should be mentioned. First, the use of a regular academic period has been suggested as useful to obtain “non-stressful” baseline values (Hazlett et al., 1997; Loft et al., 2007). To enable that the intervention lasted the whole semester and because we assumed that students had low stress during this “regular academic” period, we set the beginning of the semester as our baseline period. However, the average group HRV (and HR) values at baseline are lower (higher) in our sample compared to previous studies with student samples (Dimitriev, Dimitriev, Karpenko, & Saperova, 2008; Hazlett et al., 1997; Hughes & Stoney, 2000; Lucini et al., 2002). This may indicate a very sedentary group or more stress at baseline. For comparison, Dimitriev et al. (2008) reported LF/HF ratios ranging from 2.15 to 2.65 during baseline and from 2.65 to 4.08 during an examination period dependent upon subjective prediction of success and actual examination marks. Furthermore, there is quite a lot of between-subject variability regarding the examination period. While for some students the days immediately prior to an examination are the most stressful, other students experience more stress during the anticipation phase before exams (Sakakibara et al., 2008; Sausen et al., 1992;

Spangler, 1997). Specifically, Dimitriev et al. (2008) reported that 20% of their students sample had no HR increase from semester to examination period. While some students in our CG sample showed no decrease in HRV (and increase in HR) from baseline to the examination period, there were noticeable increases in other students of the CG. However, previous studies have demonstrated that overall examinations are useful real-life stressors (Hazlett et al., 1997; Lucini et al., 2002; Sausen et al., 1992).

Second, based on our objective accelerometer measures of physical activity, we controlled for the influence of physical activity on HRV. Although this is state of the art, future studies should also control for the influences of posture on HRV during every-day life.

Conclusion

The results of our randomized, controlled trial provide empirical support for the cross-stressor adaptation hypothesis during every-day life. Since repeated prolonged stress accompanied by enhanced dysregulation of the autonomic system increases the risk for negative health outcomes (Jarczok et al., 2013), effective preventive strategies are needed. Our results indicate that through regular AET, the regulation of the autonomic system can be improved by an attenuated physiological stress response under real-life stress. This indicates that exercise may be a useful strategy to prevent stress-related cardiovascular diseases. In addition, we demonstrated positive effects of AET during both the day and night. To the authors´ knowledge this is the first study to address the effects of regular AET on real-life stress using ambulatory measures and a randomized, controlled trial. Future studies should investigate the effects of exercise on physiological stress responses to various real-life stressors in more detail.

5 General Discussion

The current thesis examined whether regular aerobic exercise training leads to reduced emotional and physiological responses during real-life stress in young sedentary students. This final chapter summarizes and discusses the main findings, then considers methodological issues and describes implications for research. The chapter closes with some general conclusions.

In the study reported in *Chapter 2*, we analyzed whether the postulated *feel better effect* that promotes a positive association between physical activity and affect can be confirmed in sedentary individuals, too. To date, evidence for the *feel better effect* comes from studies including active and inactive people or studies that did not control for participants´ habitual physical activity level. Previous studies indicated that exercise of low to moderate intensity can induce positive affective changes in sedentary people (Ekkekakis et al., 2008), however, no study used ambulatory methods to assess unstructured physical activity and affect in every-day life. Thus, we examined whether the mean activity intensity (mean MET) and the time spent in activity of light intensity (1.6–2.9 MET) was associated with the three mood dimensions: valence, calmness and energetic arousal in young sedentary students. The analysis was conducted based on the baseline data of the randomized, controlled trial during the first year of data collection. Accelerometer based physical activity was averaged over the 15 min prior to every subsequent affect rating (7 per day over two days) captured via electronic diaries. Within-subject correlations revealed non-significant small associations between unstructured physical activity and affect with a high variability of within-subject correlations.

The results indicate that the association between unstructured physical activity and affect appears to be more complex in sedentary people. Moreover, we assume that affective reactions to unstructured physical activity differ between sedentary people. However, we could show that even activity of light intensity can change affect in some sedentary students, thus more research is needed to examine the association of unstructured physical activity of different intensities on affective changes in sedentary people. If sedentary individuals perceived unstructured light intensity activity as pleasant, promoting more light activity during daily life would be a promising strategy to introduce a more active lifestyle to less active people. Future studies should also examine whether low intensity physical activity during daily life may serve as a preventive strategy to reduce stress responses in sedentary people.

5.1 Effects of the aerobic exercise training on aerobic capacity

An effective aerobic exercise intervention (a significant improvement of VO_2max) was presumed to detect the hypothesized effects of the aerobic exercise training on real-life stress. Thus, as a manipulation check to assess the aerobic capacity, VO_2max_{rel} (ml/min/kg) was determined via cardiopulmonary exercise testing (Röcker, 2010). The results showed an average increase in VO_2max of 8.7% in the experimental and an average decrease of 5.6% in the control group (Table 2.1). Running performance[4] as another indicator of fitness changed by 8.3% in the AET group while it decreased by 9.1% in the CG. The ANCOVA revealed significance for the factor group in $VO_2max_{rel,}$ $F(1, 56) = 55.3$; $p < .001$; $\eta2 = .51$ and in running performance, $F(1, 56) = 56.7$; $p < .001$; $\eta2 = .52$ indicating a strong effect (J. Cohen, 1988) of the intervention. Previous studies depicted very heterogeneous results for VO_2max improvement after aerobic exercise training due to factors like target group, baseline vagal tone, age, gender, training load, and genetic disposition (Hautala et al., 2009). We also observed these intra-individual differences in VO_2max improvement (SD = 6.4). Our results demonstrate that a supervised and individually tailored exercise intervention of sufficient duration and aerobic intensity can lead to significant VO_2max improvements. As we additionally detected significant effects of the intervention on emotional and physiological stress reactivity, we suggest that the training schedule we used in our study is convenient to reduce stress reactivity in sedentary people.

Chapter 3 reports on the analysis of the randomized, controlled trial which was conducted in 61 male sedentary students. Participants of the experimental group completed 20 weeks of aerobic exercise training over the course of a

[4] Achieved maximal running speed in the cardiopulmonary exercise test (in km/h).

semester. The training contained two running sessions per week and included mainly aerobic activity with intervals in the aerobic-anaerobic zone and was individually tailored via heart rate target zones (Röcker, 2010). Aerobic capacity was assessed with cardiopulmonary exercise testing pre- and post-intervention (results displayed above). Using electronic diaries, emotional stress reactivity was assessed by rating perceived stress and negative affect repeatedly across the two days of the measurement period pre- (beginning of the semester) and post-intervention (academic examinations). We found that participants of the aerobic exercise training group rated lower negative affect in situations of highly perceived stress than the person-mean. Furthermore, reduced emotional stress reactivity of the aerobic exercise training group was observed for both periods of measurement (Post1, Post2) during academic examinations.

These new findings considering within-subject changes provide initial support that exercise is not only effective in reducing stress-induced negative affect in the laboratory (Rimmele et al., 2007), but also during every-day life. Chronic stress is often accompanied by accumulated negative affect which in turn leads to a higher risk for psychological and physiological disorders (Collip et al., 2013; Myin-Germeys et al., 2003; Salovey et al., 2000). Therefore, the results of *Chapter 3* support the notion that regular exercise training appears to be a useful strategy to buffer the deleterious effects of stress on health.

Chapter 4 reports on the effects of the 20-week aerobic exercise training intervention on physiological responses during real-life stress. Analyzing heart rate variability pre- (beginning of the semester) and post-intervention (during academic examinations), we tested the cross-stressor adaptation hypothesis during real-life stress. Using ambulatory ECG-measures, we assessed HRV over a 36-hour period during both baseline and academic examinations during daily routine of participants. To capture perceived stress repeatedly across the day, we used electronic diaries. In addition to baseline HRV and physical activity (assessed via accelerometry), we controlled for the influence of perceived stress on HRV during real-life stress. We found decreased physiological responses to real-life stress in the aerobic exercise training group compared to the control group illustrated by a lower LF/HF ratio and higher RMSSD in the aerobic exercise training group compared to the control group. Furthermore, we observed the reduced physiological responses during both the day and the night. The results provide empirical support for the cross-stressor adaptation hypothesis during real-life stress. The specific physiological adaptations (reflected in HRV) to repeated exercise translate to unspecific physiological responses to real-life stress. Since exaggerated cardiovascular reactivity of the autonomic nervous system has been associated with negative health outcomes (Carroll et al., 2009), these results have important implications for the prevention of stress-related cardiovascular diseases. More studies should examine the effects of controlled aerobic exercise training using real-life stressors and ambulatory assessment. Moreover, the effects of aerobic exercise on more intense and long-term real-life stressors should be investigated in more detail.

5.2 Methodological issues

Using ambulatory assessment and a real-life stressor, the present thesis translated research on the stress-exercise association into every-day life. Our methodology has several strengths:

First, we used a randomized, controlled trial to analyze the effects of 20 weeks of aerobic exercise training. In addition, the duration of 20 weeks (course of one semester) was quite long and enabled us to detect strong effects on aerobic exercise capacity.

Second, with the use of a more personally relevant real-life stressor, namely academic examinations, we enhanced the generalizability of the results compared to previous studies which used mental stress tasks in the laboratory (Crews & Landers, 1987). While laboratory studies reveal valuable information on the underlying mechanisms of stress responses under controlled conditions, they often do not appear to be generalizable to actual real-life responses (Gauvin et al., 1996; Houtveen & De Geus, 2009; Sloan et al., 2011; H. Wilhelm et al., 2012).

Third, we improved ecological validity because we assessed objective physical activity and physiological (ECG) data continuously in the students´ natural environment. We extended the results of laboratory studies showing reduced physiological stress reactivity after an aerobic exercise intervention (Klaperski et al., 2014). In addition, we controlled for unstructured physical activity throughout the intervention period and paralleled to ECG recordings. Thus we could separate activity-induced changes from stress-induced changes in physiological variables. Furthermore, we were able to capture context information (time, social contact, location, and activity) to enhance control of confounding factors.

Fourth, we gave consideration to the dynamic characteristics of stress and affect by assessing these psychological variables repeatedly over time. Allowing for situation-specific differences within subjects, we found that the effects of exercise were evident through reduced emotional reactivity (decreased negative affect) in situations of higher perceived stress.

Finally, to justify the complex associations and interdependencies of exercise and stress, more sophisticated statistical analyses are needed. Using multilevel analyses the present thesis adds important new insights because within-subject associations (e.g., perceived stress and affect) as well as between-subject associations (e.g., group and person characteristics) were analyzed at the same time. In addition, missing data and uneven numbers of observations between participants were considered (Hoffman & Rovine, 2007).

Although the current thesis revealed important findings and has several strengths, there are some critical points that should be discussed as they raise further methodological considerations for future studies:

First, we recruited young, healthy, sedentary students, thus the sample of the randomized, controlled trial is not representative. In addition, selection bias is a general problem that occurs when there is a systematic difference between either (a) those participating in the study and those who do not or (b) those in the treatment group and those in the control group of a study. The latter can be reduced via randomization but it is known from public health studies that participants, who volunteer to participate, are not representative for the general population because they are more health conscious and thus threaten the generalizability of the study results (Hennekens & Buring, 1987). Although the goal of the randomized, controlled trial to reduce stress responses was not communicated to participants, the sample may have been characterized by students who were rather less vulnerable to stress. Students knew that one assessment period was set to the academic examination period, thus students vulnerable to stress might not have enrolled in the study because exercise can be a stressor per se (Lutz et al., 2010) especially for sedentary people.

Second, average affect and perceived stress values were on a relatively high level in the present sample of young, healthy students. Identifying periods of negative affect and high perceived stress was more difficult compared to patient samples. As a consequence, there was little variance in mood and perceived stress. Although less frequent and intense, these periods of decreased affect and high perceived stress exist, thus the challenge is to capture them. Using a combined protocol (integrating event-based and time-based sampling strategies as well as physiology-triggered assessments) may be an even more suitable method for future studies (Shiffman, 2007). Furthermore, questions regarding perceived stress have to be more specified to students´ stressors, for example differentiating between stressfulness of tasks related to learning and studies, social conflicts or study-independent stressors (additional stress due to job, and financial straits).

The problem of little variance due to an infrequent occurrence of a parameter characteristic was observed in physical activity variables, too. Few episodes of moderate to vigorous activity and mainly sedentary periods characterized the sample, thus analyzing the activity-affect association was difficult. More important, students even showed infrequent occurrence of light intensity activities. To obtain more activity periods to subject to mood ratings, we recommend an intervention that promotes physical activity during the assessment period. Furthermore, the use of interactive multimodal ambulatory monitoring (Ebner-Priemer et al., 2013) is a promising approach to increase the number of electronic diary assessments during episodes of an activity of interest, for example, periods of low intensity physical activity. An accelerometer-based algorithm identifies the point whenever acceleration exceeds or falls below a predefined threshold (e.g., of low intensity) and initializes a mood assessment in this way (Bussmann et al., 2009; Ebner-Priemer et al., 2013).

Baseline measures in the laboratory can be conducted under controlled conditions. On the one hand, obtaining baseline measures in real-life settings is more challenging but on the other hand, it can prevent the influences of anticipation on baseline values, which have been observed in the laboratory (Balodis et al., 2010). To maximize within-subject differences in stress reactivity and to demonstrate the treatment effect, the present thesis used two specific real-life assessment periods. The baseline period was set to the beginning of the semester because it is a regular academic period characterized by lower stress (Loft et al., 2007). However, the physiological analysis indicated higher HRV baseline values compared to previous studies using student samples (Dimitriev et al., 2008). This may indicate either a very sedentary group or more stress at baseline. The beginning of the semester may display a period of higher stress compared to the middle of the semester due to organizational reasons and the need for students to adapt to a new schedule or routine. Thus, obtaining a useful baseline value during real-life is an important aspect to consider in future studies.

Analyzing the effects of exercise interventions on real-life stressors requires procedures different from those of laboratory studies. In light of the current thesis, it was not possible to apply the same stressor of academic examinations twice, pre- and post-intervention. The time span of several months between periods of academic examinations prevents comparisons. Furthermore, it is difficult to expect such an effort from participants. The descriptively similar baseline and examination values in the present thesis may question whether students experienced noticeable physiological stress during the examination period. However, examinations have been shown to induce noticeable stress in students (Hazlett et al., 1997; Spangler, 1997) accompanied with significantly elevated cardiovascular reactivity (Sausen et al., 1992; Zanstra & Johnston, 2011; Hazlett et al., 1997). Thus, the results should be replicated with more studies using different real-life stressors.

Most of the studies examining the effects of exercise on stress reactivity report very little about the details of the aerobic exercise intervention. To maintain aerobic fitness, an intensity of > 70% of maximum heart rate and a duration of minimally 20 min three times a week is necessary (de Geus & Stubbe, 2007). Insights about intensity may improve our understanding of exercise effects on stress, as we have learned from research on exercise and affect (Ekkekakis et al., 2011). Thus, future studies should report in detail on their training schedule used and at least report the frequency, duration and intensity of training sessions.

5.3 Implications for research

Research in psychology has investigated the associations between real-life stress and health for years (Zanstra & Johnston, 2011). Although researchers already encouraged the application of real-life stressors to investigate the exercise-stress association more than 20 years ago (Crews & Landers, 1987), only a few studies (mainly cross-sectional) have used real-life stressors. In contrast, the number of publications introducing artificial stress in the laboratory has risen from year to year. Stress is a dynamic construct dependent upon situational characteristics, and thus even when conditions are controlled, comparisons to laboratory results are impossible: only real-life stressors can reflect the behavior and behavioral responses that actually occur in real-life situations (Houtveen & De Geus, 2009). The current thesis was able to improve ecological validity by using a real-life stressor and ambulatory assessment. More randomized, controlled trials examining the effects of regular aerobic exercise on both emotional and physiological stress reactivity in real-life settings are necessary. Specifically, researchers should examine whether training-induced changes lead to attenuated stress responses in individuals who experience heavy stress.

5.3.1 The activity-affect association in inactive people

The results of *Chapter 2* indicate that in young sedentary adults, the activity-affect association is more complex compared to the picture drawn from previous studies including participants from a broad range of habitual activity levels. While, an activity-affect association was observed in some participants, unstructured physical activity was not associated to affect in others. In addition, the highest association was observed between activity and energetic arousal, while valence and calmness, in contrast to studies including active participants, showed a small association. There is growing evidence that sedentariness may contribute much to the onset of stress-related diseases (Hamer, 2012). Future studies should examine whether lightly intense activity can improve affect in sedentary individuals.

5.3.2 Regular exercise and emotional stress reactivity

As presented in more detail in the introduction, Salmon (2001) suggested that the initial aversive character of exercise diminishes through the repetition of exercise and is altered by tolerance. On the one hand, this concept may help to explain the high variability in the association between the three mood dimensions and unstructured physical activity presented in *Chapter 2*. Specifically, due to the low association of the valence dimension at baseline, one can assume that activity was perceived as rather aversive in some sedentary individuals. On the other hand these results have to be interpreted with caution because (a) few activity episodes were identified and (b) unstructured physical activity and not exercise was analyzed. The improved emotional stress reactivity post-intervention during real-life stress may reflect a shift from an aversive to a positive hedonic tone due to tolerance of repeated regular exercise training. In the present thesis, this was not reflected by an average decrease in negative affect of the aerobic exercise training group, but through lower negative affect especially in situations of high perceived stress. Thus, research has to (a) investigate if there is a point in time when sedentary individuals start to perceive exercise as pleasant, (b) examine whether there is a link between such a point and physiological adaptation to training and (c) focus on repeated assessments of within-subject adaptations to regular aerobic exercise training.

The reduced emotional stress reactivity (reduced negative affect) of the aerobic exercise training assumes that regular, and not only acute, exercise can enhance affective states, especially in situations of high perceived stress. It has been suggested that improved affective states during stress observed in longitudinal studies were measured during post-exercise windows of acute exercise. Hamer (2012) recently recommended controlling for aftereffects of a recent bout of acute exercise. The effects presented in the current thesis appear to be independent from acute exercise effects because affective states were assessed repeatedly across two days, thus it is unlikely that affect was repeatedly assessed in post-exercise windows. To get more insights, future studies should relate accelerometer measures of the preceding minutes of unstructured physical activity to emotional stress reactivity.

5.3.3 Regular exercise and physiological stress reactivity

Our findings demonstrated reduced LF/HF and increased RMSSD in participants of the aerobic exercise training group compared to the control group. While these results are encouraging and provide preliminary support that both a reduction of sympathetic and an increase in parasympathetic activity is responsible for the improved physiological responses to real-life stress, these results have to be regarded with caution. We used the LF/HF ratio as a marker of sympathovagal balance, however, its use is discussed critically (Eckberg, 1997; Malliani et al., 1998). Future studies should assess sympathetic activity with, for example, the pre-ejection period, a more distinct parameter for sympathetic activity. Furthermore, we found decreased LF/HF and increased RMSSD of the aerobic exercise training group compared to the control group during the night. These results may indicate that exercise improves nightly recovery during stressful episodes. However, these are also preliminary findings because sleep was not assessed with sophisticated multichannel EEG in a sleep laboratory.

While we continuously controlled for activity-induced changes in physiological variables, we did not consider posture. Future studies should control for posture because it has an important impact on changes in heart rate variability (Vrijkotte et al., 2000). Furthermore, objective measures of physical activity have the potential to deliver more insights about the association between exercise, physical activity, and stress. Since recent research found associations between inactivity and stress (Hamer, 2012), analyses of sedentary behavior and unstructured physical activity during every-day life should be investigated in exercise training studies that aim to reduce stress reactivity. In the randomized, controlled trial of the current thesis, physical activity was assessed only for two days because (a) the accelerometer was integrated in the ecgMove and (b) a longer assessment period of unstructured physical activity was not necessary to address our hypotheses. However, an exploratory analysis revealed that the aerobic exercise training group had a remarkable reduction of unstructured physical activity compared to the control group (data not shown). Thus, future studies should objectively assess unstructured physical activity parallel to exercise interventions to obtain important information about physical activity and sedentary behavior during stressful episodes and the impact of training on these behaviors (Hamer, 2012).

Given the results of the randomized, controlled trial presented in *Chapter 3* and *Chapter 4*, sedentary students can benefit from regular aerobic exercise training in terms of reduced emotional and physiological stress responses during real life. In this context, and considering the high dropout rate of exercise programs, the present thesis raises the question, how sedentary students exercised after the end of the structured exercise intervention. Recent studies suggest that during stressful periods, people tend to be less physically active and exercise less (Lutz et al., 2010; Sonnentag & Jelden, 2009; Stults-Kolehmainen, 2013). This holds true especially for sedentary people or people who are during earlier stages of change (Lutz et al., 2010). For example, Sherman, Bunyan, Creswell, and Jaremka (2009) found reduced exercise levels in students during examinations. These results indicate that even if regular exercise proved to be effective for reducing stress reactivity, sedentary people will probably not exercise during stressful periods, which is a discouraging assumption.

In this context, the perception of affective responses to exercise may be important. Ekkekakis et al. (2011) suggested that exercise beyond the individual′s anaerobic threshold is unpleasant and that perceived pleasantness during the exercise influences future adherence. Thus, the authors recommended that self-selected intensity and exercises that induce positive affect may improve adherence. The current thesis showed that supervised and individually tailored aerobic exercise training can improve emotional stress reactivity. To enhance the likelihood that sedentary people and persons during earlier stages of change actually exercise to reduce stress, aerobic exercise training of self-selected intensity may have a promising potential. Self-selected exercise has been shown to induce positive affective changes, thus it may encourage formerly sedentary people to use it for stress reduction. This is supported by the assumption that exercising at a higher intensity than one is used to would not help to reduce stress, probably because it does not improve affective states (Lutz et al., 2010; Salmon, 2001). In addition, research has shown that low-intensity exercise, for example walking, can induce positive affect (Ekkekakis et al., 2008). In contrast to emotional benefits of low-intensity exercise, to achieve physiological adaptations, exceeding a threshold of higher intensity has been suggested (Sothmann, 2006; Sothmann et al., 1996).

5.4 General Conclusions

Finally, we still know little about responses of our body and our mind to stress. While exaggerated physiological responses are linked to cardiovascular disease, there is growing evidence from recent studies that diminished reactivity may predict an elevated risk for adverse health outcomes like obesity or depression and addiction such as alcoholism (Carroll et al., 2009; Lovallo, 2011). Furthermore, even if stress responses are often accompanied by negative affect, they represent a normal process of physiological regulatory mechanisms to keep internal environments in order. People differ in how responsive they are to stressors and how they compensate emotionally and physiologically. However, the current thesis provides empirical support that regular exercise can buffer the detrimental effects of psychological real-life stressors. The current thesis revealed the following important results:

(a) Aerobic exercise training led to significant improvements of aerobic capacity.

(b) Aerobic exercise training led to decreased emotional responses to real-life stress. In situations of highly perceived stress, regular exercise induced less negative affect.

(c) Aerobic exercise training led to decreased physiological responses to real-life stress (illustrated by HRV).

(d) The association between unstructured physical activity and affect appeared to be more complex in sedentary people (illustrated by high variability in within-subject correlations).

More studies are necessary to replicate these preliminary findings. Based on our results future research should investigate:

- the effects of regular exercise on physiological and emotional stress reactivity under various real-life stressors (e.g. work-stress)

- the effects of regular exercise on physiological and emotional stress reactivity under real-life stressors of varying stress-intensity
- the effects of exercise on emotional stress reactivity in terms of positive affective changes (in addition to negative affect)
- changes in unstructured physical activity during aerobic exercise interventions
- effects of regular exercise training of different intensities on physiological and emotional stress responses in real-life
- follow-up measures after the end of the exercise intervention
- the effects of regular exercise on recovery after real-life stress (after academic examinations)
- the association between individual improvement in aerobic capacity and stress reactivity and identified predictors of baseline parameters
- effects of aerobic exercise training on stress reactivity in terms of non-responders and responders (why it works; for whom it works)
- the association between sedentary behavior, exercise and stress responses.

The results of the current thesis highlight how regular exercise can influence one part of the stress process, namely physiological and emotional responses to stress. Decreased emotional and physiological stress reactivity is supposed to buffer the detrimental effects of stress on mental and physical health (Hamer, 2012). The stress-regulative potential of exercise goes beyond stress responses and it is assumed that exercise can intervene in the origins of stressors and coping with stressors, too (de Geus & Stubbe, 2007; Fuchs & Klaperski, 2012). Moreover, regular exercisers may be less vulnerable to future stressors, have a higher stress threshold, a good social network and an improved self-concept (Gerber & Pühse, 2009).

Depressive disorders and cardiovascular diseases are both leading burdens of disease and responsible for health costs that already exceed billions of euros in the European Union and are rising (Nichols et al., 2012; Sobocki, Jönsson, Angst, & Rehnberg, 2006). Both are diseases that have been repeatedly associated with stress and growing evidence suggests that they are related (Kemp &

Quintana, 2013). The present thesis provides empirical support that regular exercise reduces both emotional and physiological stress reactivity to real-life stress. Thus, the present work suggests that regular exercise appears to be a useful strategy to prevent risk factors of both psychological and cardiovascular diseases. More important, in contrast to clinical treatment that aims to reduce the effects of stressors that are already present, exercise training serves as a strategy to influence the effects of stressors before they occur (Salmon, 2001). Because regular aerobic exercise has an additional major advantage, namely as a low-budget prevention, it should be prescribed and promoted much more often by physicians than it has to date. Besides jogging, there are many other possibilities to improve aerobic capacity. Participating in activities such as walking, Nordic Walking, inline-skating, cross-country skiing, swimming or cycling do not require sophisticated material and improve cardiovascular health (Knoll, Bös, & Banzer, 2006).

References

Achten, J., & Jeukendrup, A. E. (2003). Heart rate monitoring: Applications and limitations. *Sports Medicine*. doi:10.2165/00007256-200333070-00004

Ainsworth, B. E. (2009). How do I measure physical activity in my patients? Questionnaires and objective methods. *British Journal of Sports Medicine*, *43*(1), 6–9. doi:10.1136/bjsm.2008.052449

Ainsworth, B., Haskell, W., Herrmann, S., Meckes, N., Bassett, D., Tudor-Locke, C., … Leon, A. (2011). 2011 compendium of physical activities: A second update of codes and MET values. *Medicine and Science in Sports and Exercise*. doi:10.1249/MSS.0b013e31821ece12

Åkerstedt, T., Kecklund, G., & Axelsson, J. (2007). Impaired sleep after bedtime stress and worries. *Biological Psychology*, *76*(3), 170–173. doi:10.1016/j.biopsycho.2007.07.010

Albright, C., King, A., Barr Taylor, C., & Haskell, W. (1992). Effect of a six-month aerobic exercise training program on cardiovascular responsivity in healthy middle-aged adults. *Journal of Psychosomatic Research*, *36*(1), 25–36. doi:10.1016/0022-3999(92)90111-E

Anastasopoulou, P., Tansella, M., Stumpp, J., Shammas, L., & Hey, S. (2012). Classification of human physical activity and energy expenditure estimation by accelerometry and barometry. In *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS* (pp. 6451–6454). doi:10.1109/EMBC.2012.6347471

Anastasopoulou, P., Tubic, M., Schmidt, S., Neumann, R., Woll, A., & Härtel, S. (2014). Validation and comparison of two methods to assess human energy expenditure during free-living activities. *PLoS ONE*, *9*(2), 1–7. doi:10.1371/journal.pone.0090606

Anshel, M. (1996). *Effect of chronic aerobic exercise and progressive relaxation on motor performance and affect following acute stress. Behavioral medicine (Washington, D.C.)* (Vol. 21). doi:10.1080/08964289.1996.9933757

Arent, S., Landers, D., & Etnier, J. (2000). The effects of exercise on mood in older adults: A meta-analytic review. *Journal of Aging and Physical Activity*, *8*(4), 407–430.

Aubert, A. E., Seps, B., & Beckers, F. (2003). Heart Rate Variability in Athletes. *Sports Medicine*, *33*(12), 889–919. doi:10.2165/00007256-200333120-00003

Backhouse, S., Ekkekakis, P., Bidle, S., Foskett, A., & Williams, C. (2007). Exercise makes people feel better but people are inactive: paradox or artifact? *Journal of Sport & Exercise Psychology*, *29*(4), 498–517.

Baghurst, T., & Kelley, B. (2014). An examination of stress in college students over the course of a semester. *Health Promotion Practice*, *15*(3), 438–47. doi:10.1177/1524839913510316

Balodis, I. M., Wynne-Edwards, K. E., & Olmstead, M. C. (2010). The other side of the curve: Examining the relationship between pre-stressor physiological responses and stress reactivity. *Psychoneuroendocrinology*, *35*(9), 1363–1373. doi:10.1016/j.psyneuen.2010.03.011

Baquet, G., van Praagh, E., & Berthoin, S. (2003). Endurance training and aerobic fitness in young people. *Sports Medicine*, *33*(15), 1127–1143. doi:10.2165/00007256-200333150-00004

Bauman, A., Bull, F., Chey, T., Craig, C. L., Ainsworth, B. E., Sallis, J. F., … Pratt, M. (2009). The International Prevalence Study on Physical Activity: results from 20 countries. *The International Journal of Behavioral Nutrition and Physical Activity*, *6*, 21. doi:10.1186/1479-5868-6-21

Baumeister, R. F., Vohs, K. D., DeWall, C. N., & Zhang, L. (2007). How emotion shapes behavior: feedback, anticipation, and reflection, rather than direct causation. *Personality and Social Psychology Review*, *11*(2), 167–203. doi:10.1177/1088868307301033

Berger, B. G., & Motl, R. W. (2000). Exercise and mood: A selective review and synthesis of research employing the profile of mood states. *Journal of Applied Sport Psychology*, *12*(1), 69–92. doi:10.1080/10413200008404214

Bixby, R., & Lochbaum, R. (2006). Affect responses to acute bouts of aerobic exercise in fit and unfit participants: An examination of opponent-process theory. *Journal of Sport Behavior*, *29*(2), 111–125. Retrieved from http://proxy.lib.sfu.ca/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=20838153&site=ehost-live

Blair, S., & Morris, J. N. (2009). Healthy hearts-and the universal benefits of being physically active: physical activity and health. *Annals of Epidemiology*, *19*(4), 253–256. doi:10.1016/j.annepidem.2009.01.019

Blumenthal, J., Babyak, M. A., Doraiswamy, P. M., Hoffman, B. M., Barbour, K. A., Herman, S., … Sherwood, A. (2009). Exercise and pharmacotherapy in the treatment of major depressive disorder. *Psychosomatic Medicine*, *69*(7), 587–596. doi:10.1097/PSY.0b013e318148c19a.Exercise

Bolger, N., DeLongis, A., Kessler, R., & Schilling, E. (1989). The effects of daily stress on negative mood. *Journal of Personality and Social Psychology*, *57*(5), 808–818.

Bolger, N., & Schilling, E. A. (1991). Personality and the problems of everyday life: the role of neuroticism in exposure and reactivity to daily stressors. *Journal of Personality*, *59*(3), 355–386. doi:Article

Borg, G. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*(5), 377–381. doi:10.1249/00005768-198205000-00012

Bortz, J., & Schuster, C. (2010). *Statistik für Human- und Sozialwissenschaftler* (7th ed.). Berlin: Springer.

Bös, K., Worth, A., Opper, E., Oberger, J., Romahn, N., Wagner, M., … Woll, A. (2009). *Motorik Modul: Eine Studie zur motorischen Leistungsfähigkeit und körperlich-sportlichen Aktivität von Kindern und Jugendlichen in Deutschland* (Band 5.). Baden-Baden.

Bossmann, T., Kanning, M., Koudela-Hamila, S., Hey, S., & Ebner-Priemer, U. W. (2013). The association between short periods of everyday life activities and affective states: a replication study using ambulatory assessment. *Frontiers in Psychology*, *4*, 102. doi:10.3389/fpsyg.2013.00102

Brooke, S., & Long, B. (1987). Efficiency of coping with a real-life stressor: a multimodal comparison of aerobic fitness. *Psychophysiology*. doi:10.1111/j.1469-8986.1987.tb00275.x

Brosschot, J. F., & Thayer, J. F. (2003). Heart rate response is longer after negative emotions than after positive emotions, *50*(3), 181–187. doi:10.1016/S0167-8760(03)00146-6

Brown, W. J., Bauman, a E., & Owen, N. (2009). Stand up, sit down, keep moving: turning circles in physical activity research? *British Journal of Sports Medicine*, *43*(2), 86–88. doi:10.1136/bjsm.2008.055285

Bussmann, J., Ebner-Priemer, U. W., & Fahrenberg, J. (2009). Ambulatory activity monitoring: Progress in measurement of activity, posture, and specific motion patterns in daily life. *European Psychologist*, *14*(2), 142–152. doi:10.1027/1016-9040.14.2.142

Cacioppo, J., Berntson, G., Binkley, P. ., Quigley, K. S., Uchino, B. N., & Fieldstone, A. (1994). Autonomic cardiac control. II. Noninvasive indices and basal response as revealed by autonomic blockades. *Psychophysiology*, *31*(6), 586–598. doi:10.1111/j.1469-8986.1994.tb02351.x

Cacioppo, J., Berntson, G., Malarkey, W., Kiecolt-Glaser, J. K., Sheridan, J. F., Poehlmann, K. M., … Glaser, R. (1998). Autonomic, neuroendocrine, and immune responses to psychological stress: The reactivity hypothesis. *Annals of the New York Academy of Sciences*, *840*, 664–673. doi:10.1111/j.1749-6632.1998.tb09605.x

Calvo, M. G., Szabo, A., & Capafons, J. (1996). Anxiety and heart rate under psychological stress: The effects of exercise-training. *Anxiety, Stress, and Coping*, *9*(4), 321–337. doi:10.1080/10615809608249409

Camhi, S. M., Sisson, S. B., Johnson, W. D., Katzmarzyk, P. T., & Tudor-Locke, C. (2011). Accelerometer-determined moderate intensity lifestyle activity and cardiometabolic health. *Preventive Medicine*, *52*(5), 358–360. doi:10.1016/j.ypmed.2011.01.030

Campbell, J., & Ehlert, U. (2012, August). Acute psychosocial stress: Does the emotional stress response correspond with physiological responses? *Psychoneuroendocrinology*. doi:10.1016/j.psyneuen.2011.12.010

Cannon, W. (1932). *The wisdom of the body*. New York: Norton.

Carels, R., Berger, B., & Darby, L. (2006). The association between mood states and physical activity in postmenopausal, obese, sedentary women. *Journal of Aging and Physical Activity*, *14*(1), 12–28.

Carels, R., Blumenthal, J., & Sherwood, A. (2000). Emotional responsivity during daily life: relationship to psychosocial functioning and ambulatory blood pressure. *International Journal of Psychophysiology*, *36*, 25–33. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10700620

Carroll, D., Lovallo, W., & Phillips, A. (2009). Are Large Physiological Reactions to Acute Psychological Stress Always Bad for Health? *Social and Personality Compass*, *3*, 725–743. doi:10.1111/j.1751-9004.2009.00205.x

Carter, J. B., Banister, E. W., & Blaber, A. P. (2003). Effect of endurance exercise on autonomic control of heart rate. *Sports Medicine*, *33*(1), 33–46. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12477376

Centers for Disease Control and Prevention. (2008). Centers for Disease Control and Prevention. Retrieved November 23, 2012, from http://www.cdc.gov/

Childs, E., & de Wit, H. (2014). Regular exercise is associated with emotional resilience to acute stress in healthy adults. *Frontiers in Physiology*, *5*, 161. doi:10.3389/fphys.2014.00161

Chrousos, G. P. (2009). Stress and disorders of the stress system. *Nature Reviews. Endocrinology*, *5*(7), 374–381. doi:10.1038/nrendo.2009.106

Clays, E., De Bacquer, D., Crasset, V., Kittel, F., De Smet, P., Kornitzer, M., … 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. doi:10.1007/s00420-010-0537-z

Clifford, G. D., McSharry, P. E., & Tarassenko, L. (2002). Characterizing artefact in the normal human 24-hour RR time series to aid identification and artificial replication of circadian variations in human beat to beat heart rate using a simple threshold. *Computers in Cardiology*, *2002*(38), 129–132. doi:10.1109/CIC.2002.1166724

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale: Erlbaum.

Cohen, S., Kessler, R., & Gordon, L. (1997). Strategies for measuring stress in studies of psychiatric and physical disorders. In S. Cohen, R. Kessler, & L. Gordon (Eds.), *Measuring stress* (pp. 6–7). New York: Oxford University Press.

Cole, R. J., Kripke, D. F., Gruen, W., Mullaney, D. J., & Gillin, J. C. (1992). Automatic sleep/wake identification from wrist activity. *Sleep*, *15*(5), 461–469.

Collip, D., Wigman, J. T., Myin-Germeys, I., Jacobs, N., Derom, C., Thiery, E., … van Os, J. (2013). From Epidemiology to Daily Life: Linking Daily Life Stress Reactivity to Persistence of Psychotic Experiences in a Longitudinal General Population Study. *PLoS ONE*, *8*(4), e62688. doi:10.1371/journal.pone.0062688

Contrada, R. (2011). Stress, adaptation, and health. In R. Contrada & A. Baum (Eds.), *The handbook of stress science:biology, psychology, and health* (p. 1). New York: Springer.

Crews, D. J., & Landers, D. M. (1987). A meta-analytic review of aerobic fitness and reactivity to psychosocial stressors. *Medicine and Science in Sports and Exercise*, *19*(5 Suppl), S114–S120. doi:10.1249/00005768-198710001-00004

Daley, A. J., & Welch, A. (2003). Subjective exercise experiences during and after high and low intensity exercise in active and inactive adult females: Some preliminary findings. *Journal of Sports Medicine and Physical Fitness*, *43*(2), 220–222.

De Geus, E., & Stubbe, J. (2007). Aerobic Exercise and Stress Reduction. In (G. Fink, Ed.)*Encyclopedia of Stress*. New York: Elsevier Academic Press.

De Geus, E., van Doornen, L., & Orlebeke, J. (1993). Regular exercise and aerobic fitness in relation to psychological make-up and physiological stress reactivity. *Psychosomatic Medicine*, *55*, 347–363. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8416085

DeLongis, A., Folkman, S., & Lazarus, R. S. (1988). The impact of daily stress on health and mood: psychological and social resources as mediators. *Journal of Personality and Social Psychology*, *54*(3), 486–495. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3361420

Dimitriev, D., Dimitriev, A., Karpenko, Y., & Saperova, E. (2008). Influence of examination stress and psychoemotional characteristics on the blood pressure and heart rate regulation in female students. *Human Physiology*. doi:10.1134/S0362119708050101

Dimsdale, J. (2008). Psychological Stress and Cardiovascular Disease. *Journal of the American College of Cardiology*, *51*(13), 1237–1246. doi:10.1016/j.jacc.2007.12.024

Dishman, R. (1990). Determinants of participation in physical activity. In V. Bouchard, R. Shepard, T. Stevens, & J. Sutton (Eds.), *Exercise, fitness and health: A consensus of current knowledge* (pp. 75–100). Champaign, IL: Human Kinetics.

Earnest, C. P., Lavie, C. J., Blair, S., & Church, T. S. (2008). Heart rate variability characteristics in sedentary postmenopausal women following six months of exercise training: The DREW study. *PLoS ONE*, *3*(6), 1–7. doi:10.1371/journal.pone.0002288

Ebner-Priemer, U. W., Koudela, S., Mutz, G., & Kanning, M. (2013). Interactive multimodal ambulatory monitoring to investigate the association between physical activity and affect. *Frontiers in Psychology*, *3*, 596. doi:10.3389/fpsyg.2012.00596

Ebner-Priemer, U. W., & Trull, T. J. (2009). Ambulatory assessment: An innovative and promising approach for clinical psychology. *European Psychologist*, *14*(2), 109–119. doi:10.1027/1016-9040.14.2.109

Eckberg, D. L. (1997). Sympathovagal balance : A critical appraisal. *Circulation*, *96*(9), 3224–3232. doi:10.1161/01.CIR.96.9.3224

Ekkekakis, P., & Acevedo, E. (2006). Affective responses to acute exercise: Toward a psychobiological dose-response model. In E. Acevedo & P. Ekkekakis (Eds.), *Psychobiology of Physical Activity* (pp. 91–104). Champaign, IL: Human Kinetics.

Ekkekakis, P., Backhouse, S., Gray, C., & Lind, E. (2008). Walking is popular among adults but is it pleasant? A framework for clarifying the link between walking and affect as illustrated in two studies. *Psychology of Sport and Exercise*, *9*(3), 246–264. doi:10.1016/j.psychsport.2007.04.004

Ekkekakis, P., Hall, E., & Petruzzello, S. (2005). Variation and homogeneity in affective responses to physical activity of varying intensities: an alternative perspective on dose-response based on evolutionary considerations. *Journal of Sports Sciences*, *23*(5), 477–500. doi:10.1080/02640410400021492

Ekkekakis, P., Hall, E., VanLanduyt, L., & Petruzzello, S. (2000). Walking in (affective) circles: Can short walks enhance affect? *Journal of Behavioral Medicine*, *23*(3), 245–275. doi:10.1023/A:1005558025163

Ekkekakis, P., Parfitt, G., & Petruzzello, S. J. (2011). The pleasure and displeasure people feel when they exercise at different intensities: Decennial update and progress towards a tripartite rationale for exercise intensity prescription. *Sports Medicine*, *41*(8), 641–671. doi:10.2165/11590680-000000000-00000

Ekkekakis, P., & Petruzzello, S. (1999). Acute aerobic exercise and affect. Current status, problems and prospects regarding dose-response. *Sports Medicine*. doi:10.2165/00007256-199928050-00005

Eleuteri, A., Fisher, A., Groves, D., & Dewhurst, C. (2012). An efficient time-varying filter for detrending and bandwidth limiting the heart rate variability tachogram without resampling: MATLAB open-source code and internet web-based implementation. *Computational and Mathematical Methods in Medicine*, *2012*, 1–6. doi:10.1155/2012/578785

Fahrenberg, J., Brügner, G., Foerster, F., & Käppler, C. (1999). Ambulatory assessment of diurnal changes with a hand-held computer: Mood, attention and morningness–eveningness. *Personality and Individual Differences*, *26*, 641–656. doi:10.1016/S0191-8869(98)00160-3

Fahrenberg, J., Myrtek, M., Pawlik, K., & Perrez, M. (2007). Ambulatory Assessment - Monitoring behavior in daily life settings. *European Journal of Psychological Assessment*, *23*, 206–213. doi:10.1027/1015-5759.23.4.206

FAO/WHO/UNU. (1985). *Energy and Protein Requirements: Report of a joint FAO/WHO/UNU Expert Consultation*. Genua.

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*, 723–739. doi:10.1037/0278-6133.25.6.723

Fuchs, R., & Klaperski, S. (2012). Sportliche Aktivität und Stressregulation. In R. Fuchs & W. Schlicht (Eds.), *Seelische Gesundheit und sportliche Aktivität* (pp. 100–121). Göttingen: Hogrefe.

Gauvin, L., Rejeski, W. J., & Norris, J. L. (1996). A naturalistic study of the impact of acute physical activity on feeling states and affect in women. *Health Psychology*, *15*(5), 391–397. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8891718

Gerber, M. (2008). Sportliche Aktivität und Stressreaktivität: Ein review. *Deutsche Zeitschrift Für Sportmedizin*, *59*(7-8), 168–174. Retrieved from http://www.zeitschrift-sportmedizin.de/fileadmin/externe_websites/ext.dzsm/content/archiv2008/heft07_08/ArtikelGerber.pdf

Gerber, M., & Pühse, U. (2009). Do exercise and fitness protect against stress-induced health complaints? A review of the literature. *Scandinavian Journal of Public Health*, *37*, 801–819. doi:10.1177/1403494809350522

Giacobbi, P., Hausenblas, H., & Frye, N. (2005). A naturalistic assessment of the relationship between personality, daily life events, leisure-time exercise, and mood. *Psychology of Sport and Exercise*, *6*, 67–81. doi:10.1016/j.psychsport.2003.10.009

Giacobbi, P., Tuccitto, D., & Frye, N. (2007). Exercise, affect, and university students' appraisals of academic events prior to the final examination period. *Psychology of Sport and Exercise*, *8*, 261–274. doi:10.1016/j.psychsport.2006.04.001

Goedhart, A. D., Van Der Sluis, S., Houtveen, J. H., Willemsen, G., & De Geus, E. J. C. (2007). Comparison of time and frequency domain measures of RSA in ambulatory recordings. *Psychophysiology*, *44*(2), 203–215. doi:10.1111/j.1469-8986.2006.00490.x

Goldin, P., Ziv, M., Jazaieri, H., Hahn, K., & Gross, J. J. (2013). MBSR vs aerobic exercise in social anxiety: fMRI of emotion regulation of negative self-beliefs. *Social Cognitive and Affective Neuroscience*, *8*(1), 65–72. doi:10.1093/scan/nss054

Hallgren, M. Å., Moss, N. D., & Gastin, P. (2010). Regular exercise participation mediates the affective response to acute bouts of vigorous exercise. *Journal of Sports Science and Medicine*, *9*(4), 629–637.

Hallman, D. M., & Lyskov, E. (2012). Autonomic regulation, physical activity and perceived stress in subjects with musculoskeletal pain: 24-hour ambulatory monitoring. *International Journal of Psychophysiology*, *86*(3), 276–282. doi:10.1016/j.ijpsycho.2012.09.017

Hamer, M. (2012). Psychosocial Stress and Cardiovascular Disease Risk: The Role of Physical Activity. *Psychosomatic Medicine*, *74*, 896–903. doi:10.1097/PSY.0b013e31827457f4

Hamer, M., Taylor, A., & Steptoe, A. (2006). The effect of acute aerobic exercise on stress related blood pressure responses: A systematic review and meta-analysis. *Biological Psychology*, *71*(2), 183–190. doi:10.1016/j.biopsycho.2005.04.004

Hamilton, M., Hamilton, D., & Zderic, T. (2004). Exercise physiology versus inactivity physiology: an essential concept for understanding lipoprotein lipase regulation. *Exercise and Sport Sciences Reviews*, *32*(4), 161–166. doi:10.1097/00003677-200410000-00007

Hamilton, M., Hamilton, D., & Zderic, T. (2007). Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. *Diabetes*, *56*, 2655–2667. doi:10.2337/db07-0882.CVD

Hamilton, P. (2002). Open source ECG analysis. *Computers in Cardiology*, *29*, 101–104. doi:10.1109/CIC.2002.1166717

Haskell, W. L., Lee, I.-M., Pate, R. R., Powell, K. E., Blair, S., Franklin, B. A., … Bauman, A. (2007). Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation*, *116*(9), 1081–1093. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17671237

Hautala, A. J., Kiviniemi, A. M., & Tulppo, M. P. (2009). Individual responses to aerobic exercise: The role of the autonomic nervous system. *Neuroscience and Biobehavioral Reviews*, *33*, 107–115. doi:10.1016/j.neubiorev.2008.04.009

Hautala, A. J., Mäkikallio, T. H., Kiviniemi, A., Laukkanen, R. T., Nissilä, S., Huikuri, H. V, & Tulppo, M. P. (2003). Cardiovascular autonomic function correlates with the response to aerobic training in healthy sedentary subjects. *American Journal of Physiology, Heart and Circulatory Physiology*, *285*(4), H1747–H1752. doi:10.1152/ajpheart.00202.2003

Hautala, A. J., Mäkikallio, T. H., Kiviniemi, A., Laukkanen, R. T., Nissilä, S., Huikuri, H. V, & Tulppo, M. P. (2004). Heart rate dynamics after controlled training followed by a home-based exercise program. *European Journal of Applied Physiology*, *92*(3), 289–297. doi:10.1007/s00421-004-1077-6

Hazlett, R. L., Falkin, S., Lawhorn, W., Friedman, E., & Haynes, S. N. (1997). Cardiovascular reactivity to a naturally occurring stressor: Development and psychometric evaluation of a psychophysiological assessment procedure. *Journal of Behavioral Medicine*, *20*(6), 551–570. doi:10.1023/A:1025566408046

Healy, G., Dunstan, D., Salmon, J., Cerin, E., Shaw, J., Zimmet, P., & Owen, N. (2008). Breaks in sedentary time. Beneficial associations with metabolic risk. *Diabetes Care*, *31*(4), 661–666. doi:10.2337/dc07-2046

Hennekens, C., & Buring, J. (1987). *Epidemiology in medicine*. (S. Mayrent, Ed.). Philadelphia: Lippincott Williams & Wilkins.

Hoffman, L., & Rovine, M. J. (2007). Multilevel models for the experimental psychologist: foundations and illustrative examples. *Behavior Research Methods*, *39*(1), 101–117. doi:10.3758/BF03192848

Holmes, D. S., & Roth, D. L. (1988). Effects of aerobic exercise training and relaxation training on cardiovascular activity during psychological stress. *Journal of Psychosomatic Research*, *32*(4-5), 469–474. doi:10.1016/0022-3999(88)90031-1

Houtveen, J. H., & De Geus, E. J. C. (2009). Noninvasive psychophysiological ambulatory recordings: Study design and data analysis strategies. *European Psychologist*, *14*(2), 132–141. doi:10.1027/1016-9040.14.2.132

Hughes, J. W., & Stoney, C. M. (2000). Depressed mood is related to high-frequency heart rate variability during stressors. *Psychosomatic Medicine*, *62*(6), 796–803. doi:0033-3174/00/6206-0796

Hyde, A. L., Conroy, D. E., Pincus, A. L., & Ram, N. (2011). Unpacking the feel-good effect of free-time physical activity: between- and within-person associations with pleasant-activated feeling states. *Journal of Sport & Exercise Psychology*, *33*(6), 884–902. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/22262710

Ice, G., & James, G. (2006). Conducting a field study of stress: general principles. In G. Ice & G. James (Eds.), *Measuring stress in Humans: A practical guide for the field* (pp. 3–24). Cambridge: Cambridge University Press.

Jackowska, M., Dockray, S., Endrighi, R., Hendrickx, H., & Steptoe, A. (2012). Sleep problems and heart rate variability over the working day. *Journal of Sleep Research*, *21*(4), 434–440. doi:10.1111/j.1365-2869.2012.00996.x

Jackson, E. M., & Dishman, R. K. (2006). Cardiorespiratory fitness and laboratory stress: a meta-regression analysis. *Psychophysiology*, *43*, 57–72. doi:10.1111/j.1469-8986.2006.00373.x

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 and Biobehavioral Reviews*, *37*(8), 1810–23. doi:10.1016/j.neubiorev.2013.07.004

Jekauc, D., Wagner, M. O., Kahlert, D., & Woll, A. (2013). Reliability and validity of MoMo-Physical-Activity-Questionnaire for adolescents (MoMo-AFB). *Diagnostica*, *59*(2), 100–111. doi:10.1026/0012-1924/a000083

Joyner, M., & Green, D. (2009). Exercise protects the cardiovascular system: effects beyond traditional risk factors. *The Journal of Physiology*, *587*(23), 5551–5558. doi:10.1113/jphysiol.2009.179432

Julian, K., Beard, C., Schmidt, N. B., Powers, M. B., & Smits, J. A. (2012). Attention training to reduce attention bias and social stressor reactivity: an attempt to replicate and extend previous findings. *Behaviour Research and Therapy*, *50*, 350–358. doi:10.1016/j.brat.2012.02.015

Kanning, M., Ebner-Priemer, U. W., & Brand, R. (2012). Autonomous regulation mode moderates the effect of actual physical activity on affective states: an ambulant assessment approach to the role of self-determination. *Journal of Sport & Exercise Psychology*, *34*(2), 260–269. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/22605366

Kanning, M., & Schlicht, W. (2010). Be active and become happy: an ecological momentary assessment of physical activity and mood. *Journal of Sport & Exercise Psychology*, *32*(2), 253–261.

Kemp, A., & Quintana, D. (2013). The relationship between mental and physical health: Insights from the study of heart rate variability. *International Journal of Psychophysiology*, *89*(3), 288–296. doi:10.1016/j.ijpsycho.2013.06.018

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*, 266–274. doi:10.1016/j.psychsport.2012.11.003

Klaperski, S., von Dawans, B., Heinrichs, M., & Fuchs, R. (2014). Effects of a 12-week endurance training program on the physiological response to psychosocial stress in men: a randomized controlled trial. *Journal of Behavioral Medicine*, *37*, 1118–1133. doi:10.1007/s10865-014-9562-9

Knoll, M., Bös, K., & Banzer, W. (2006). Aktivität und physische Gesundheit. In K. Bös & W. Brehm (Eds.), *Handbuch Gesundheitssport:* (2nd ed., p. 129). Schorndorf: Hofmann.

Koster, A., Caserotti, P., Patel, K. V., Matthews, C. E., Berrigan, D., van Domelen, D. R., … Harris, T. B. (2012). Association of sedentary time with mortality independent of moderate to vigorous physical activity. *PLoS ONE*, *7*(6), 1–8. doi:10.1371/journal.pone.0037696

Krantz, D., & Manuck, S. (1984). Acute psychophysiologic reactivity and risk of cardiovascular disease: a review and methodologic critique. *Psychological Bulletin*, *96*(3), 435–464. doi:10.1037/0033-2909.96.3.435

Landers, D., & Arent, S. (2001). Exercise and mental health. In R. Singer, H. Hausenblas, & C. Janelle (Eds.), *Handbook of Sport Psychology* (2nd ed., pp. 740–765). New York: John Wiley & Sons Inc.

Lazarus, R. S. (2000). Toward better research on stress and coping. *American Psychologist*, *55*, 665–673. doi:10.1037//0003-066X.55.6.665

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

Lin, Y. H., Chen, C. Y., Lin, S. H., Liu, C. H., Weng, W. H., Kuo, T. B. J., & Yang, C. C. H. (2013). Gender differences in cardiac autonomic modulation during medical internship. *Psychophysiology*, *50*(6), 521–527. doi:10.1111/psyp.12038

Lindgren, M., Alex, C., Shapiro, P., Mckinley, P., Brondolo, E., Myers, M., … Sloan, R. (2013). Effects of aerobic conditioning on cardiovascular sympathetic response to and recovery from challenge. *Psychophysiology*, *50*, 963–973. doi:10.1111/psyp.12078

Loft, P., Thomas, M. G., Petrie, K. J., Booth, R. J., Miles, J., & Vedhara, K. (2007). Examination stress results in altered cardiovascular responses to acute challenge and lower cortisol. *Psychoneuroendocrinology*, *32*(4), 367–375. doi:10.1016/j.psyneuen.2007.02.004

Lovallo, W. (2005). *Stress & Health. Biological and psychological interactions* (2nd ed.). Thousand Oaks: Sage Publications.

Lovallo, W. (2011). Do low levels of stress reactivity signal poor states of health? *Biological Psychology*, *86*(2), 121–128. doi:10.1016/j.biopsycho.2010.01.006

Lucini, D., Di Fede, G., Parati, G., & Pagani, M. (2005). Impact of chronic psychosocial stress on autonomic cardiovascular regulation in otherwise healthy subjects. *Hypertension*, *46*(5), 1201–1206. doi:10.1161/01.HYP.0000185147.32385.4b

Lucini, D., Norbiato, G., Clerici, M., & Pagani, M. (2002). Hemodynamic and autonomic adjustments to real life stress conditions in humans. *Hypertension*, *39*(1), 184–188. doi:10.1161/hy0102.100784

Lutz, R. S., Stults-Kolehmainen, M. A., & Bartholomew, J. B. (2010). Exercise caution when stressed: Stages of change and the stress–exercise participation relationship. *Psychology of Sport and Exercise*, *11*, 560–567. doi:10.1016/j.psychsport.2010.06.005

Maier, S., & Seligman, M. (1976). Learned helplessness: Theory and evidence. *Journal of Experimental Psychology*, *105*(1), 3–46. doi:10.1037/0096-3445.105.1.3

Malliani, A., Pagani, M., Montano, N., & Mela, G. S. (1998). Sympathovagal balance: a reappraisal. *Circulation*, *98*(23), 2640–2643. doi:10.1161/01.CIR.98.23.2640.a

McEwen, B., & Stellar, E. (1993). Stress and the inidividual. Mechanisms leading to disease. *Archives of Internal Medicine*, *153*(18), 2093.

Meyer, A. (1951). *The life charta and the obligation of specifying positive data in psycho-pathological diagnosis*. *The collected papers of Adolf Meyer, Vol.3: Medical teaching* (3rd ed.). Baltimore: The Johns Hopkins University Press.

Meyer, T., & Kindermann, W. (1999). Die maximale Sauerstoffaufnahme. *Deutsche Zeitschrift Für Sportmedizin*, *50*(9), 285–286.

Myin-Germeys, I., Krabbendam, L., Delespaul, P. A. E. G., & van Os, J. (2003). Do life events have their effect on psychosis by influencing the emotional reactivity to daily life stress? *Psychological Medicine*, *33*, 327–333. doi:10.1017/S0033291702006785

Myin-Germeys, I., van Os, J., Schwartz, J. E., Stone, A. A., & Delespaul, P. A. (2001). Emotional reactivity to daily life stress in psychosis. *Archives of General Psychiatry*, *58*, 1137–1144. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11735842

Myrtek, M. (2004). *Heart and Emotion. Ambulatory monitoring studies in every-day life*. Seattle, WA: Hogrefe & Huber.

Nguyen-Michel, S., Unger, J., Hamilton, J., & Spruijt-Metz, D. (2006). Associations between physical activity and perceived stress/hassles in college students. *Stress and Health*, *22*, 179–188. doi:10.1002/smi.1094

Nichols, M., Townsend, N., Luengo-Fernandez, R., Leal, J., Gray, A., Scarborough, P., & Rayner, M. (2012). *European Cardiovascular Disease Statistics 2012*. Brussels.

Norris, R., Carroll, D., & Cochrane, R. (1992). The effects of physical activity and exercise training on psychological stress and well-being in an adolescent population. *Journal of Psychosomatic Research*, *36*, 55–65. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1538350

Nummela, A., Hynynen, E., Kaikkonen, P., & Rusko, H. (2010). Endurance performance and nocturnal HRV indices. *International Journal of Sports Medicine*, *31*(3), 154–159. doi:10.1055/s-0029-1243221

Oaten, M., & Cheng, K. (2005). Academic examination stress impairs self–control. *Journal of Social and Clinical Psychology*, *24*, 254–279. doi:10.1521/jscp.24.2.254.62276

Oaten, M., & Cheng, K. (2006). Improved self-control: The benefits of a regular program of academic study. *Basic and Applied Social Psychology*, *28*(1), 1–16. doi:10.1207/s15324834basp2801_1

Owen, N., Healy, G. N., Matthews, C. E., & Dunstan, D. W. (2010). Too much sitting: the population health science of sedentary behavior. *Exercise and Sport Sciences Reviews*, *38*(3), 105–113. doi:10.1097/JES.0b013e3181e373a2

Owen, N., Sparling, P. B., Healy, G. N., Dunstan, D. W., & Matthews, C. E. (2010). Sedentary behavior: emerging evidence for a new health risk. *Mayo Clinical Proceedings*, *85*(12), 1138–1141. doi:10.4065/mcp.2010.0444

Petruzzello, S., Landers, D., Hatfield, B., Kubitz, K., & Salazar, W. (1991). A meta-analysis on the anxiety-reducing effects of acute and chronic exercise. Outcomes and mechanisms. *Sports Medicine*, *11*(3), 143–182. doi:10.2165/00007256-199111030-00002

Phillips, A. (2011). Blunted cardiovascular reactivity relates to depression, obesity, and self-reported health. *Biological Psychology*, *86*(2), 106–113. doi:10.1016/j.biopsycho.2010.03.016

Pichot, V., Bourin, E., Roche, F., Garet, M., Gaspoz, J. M., Duverney, D., … Barthélémy, J. C. (2002). Quantification of cumulated physical fatigue at the workplace. *Pflugers Archiv European Journal of Physiology*, *445*(2), 267–272. doi:10.1007/s00424-002-0917-7

Poole, L., Steptoe, A., Wawrzyniak, A. J., Bostock, S., Mitchell, E. S., & Hamer, M. (2011). Associations of objectively measured physical activity with daily mood ratings and psychophysiological stress responses in women. *Psychophysiology*, *48*(8), 1165–1172. doi:10.1111/j.1469-8986.2011.01184.x

Prince, S., Adamo, K., Hamel, M., Hardt, J., 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

Puterman, E., O’Donovan, A., Adler, N. E., Tomiyama, J., Kemeny, M., Wolkowitz, O. M., & Epel, E. (2011). Physical activity moderates effects of stressor-induced rumination on cortisol reactivity. *Psychosomatic Medicine*, *73*, 604–611. doi:10.1097/PSY.0b013e318229e1e0

Rau, R. (2004). Lern- und gesundheitsförderliche Arbeitsgestaltung: Eine empirische Studie. *Zeitschrift Für Arbeits- Und Organisationspsychologie*, *48*(4), 181–192. doi:10.1026/0932-4089.48.4.181

Rau, R., Georgiades, A., Fredrikson, M., Lemne, C., & de Faire, U. (2001). Psychosocial work characteristics and perceived control in relation to cardiovascular rewind at night. *Journal of Occupational Health Psychology*, *6*(3), 171–181. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11482630

Reed, J., & Buck, S. (2009). The effect of regular aerobic exercise on positive-activated affect: A meta-analysis. *Psychology of Sport and Exercise*, *10*, 581–594. doi:10.1016/j.psychsport.2009.05.009

Reed, J., & Ones, D. S. (2006). The effect of acute aerobic exercise on positive activated affect: A meta-analysis. *Psychology of Sport and Exercise*, *7*(5), 477–514. doi:10.1016/j.psychsport.2005.11.003

Rethorst, C., Wipfli, B., & Landers, D. (2009). The antidepressive effects of exercise: A meta-analysis of randomized trials. *Sports Medicine*, *39*(6), 491–511. doi:10.2165/00007256-200939060-00004

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*, 190–198. doi:10.1016/j.psyneuen.2008.08.023

Rimmele, U., Zellweger, B. C., Marti, B., Seiler, R., Mohiyeddini, C., Ehlert, U., & Heinrichs, M. (2007). Trained men show lower cortisol, heart rate and psychological responses to psychosocial stress compared with untrained men. *Psychoneuroendocrinology*, *32*, 627–635. doi:10.1016/j.psyneuen.2007.04.005

Ritvanen, T., Louhevaara, V., Helin, P., Halonen, T., & Hänninen, O. (2007). Effect of Aerobic Fitness on the Physiological Stress Responses at Work. *International Journal of Occupational Medicine and Environmental Health*, *20*(1), 1–8. doi:10.2478/v10001-007-0005-5

Rivera-Brown, A., & Frontera, W. (2012). Principles of exercise physiology: Responses to acute exercise and long-term adaptations to training. *PM and R*, *4*(11), 797–804. doi:10.1016/j.pmrj.2012.10.007

Röcker, K. (2010). Verfahren zur Leistungsdiagnostik und Trainingssteuerung. In H. H. Dickhut, F. Mayer, K. Röcker, & A. Berg (Eds.), *Sportmedizin für Ärzte: Lehrbuch auf der Grundlage des Weiterbildungssystems der Deutschen Gesellschaft für Sportmedizin und Prävention (DGSP)* (2nd ed., p. 71). Köln: Deutscher Ärzteverlag.

Roecker, K. (2007). Sportmedizin für Ärzte. Lehrbuch auf der Grundlage des Weiterbildungssystems der Deutschen Gesellschaft für Sportmedizin und Prävention (DGSP). In H. H. Dickhut, F. Mayer, K. Röcker, & A. Berg (Eds.), (pp. 70–72). Köln: Deutscher Ärzteverlag.

Saito, K., Hiya, A., Uemura, Y., & Furuta, M. (2008). Clinical training stress and autonomic nervous function in female medical technology students: analysis of heart rate variability and 1/f fluctuation. *The Journal of Medical Investigation*, *55*(3-4), 227–230. doi:JST.JSTAGE/jmi/55.227

Sakakibara, M., Kanematsu, T., Yasuma, F., & Hayano, J. (2008). Impact of real-world stress on cardiorespiratory resting function during sleep in daily life. *Psychophysiology*, *45*(4), 667–670. doi:10.1111/j.1469-8986.2008.00665.x

Salmon, P. (2001). Effects of physical exercise on anxiety, depression, and sensitivity to stress: a unifying theory. *Clinical Psychology Review*, *21*(1), 33–61. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11148895

Salovey, P., Rothman, A., Detweiler, J. B., & Steward, W. T. (2000). Emotional states and physical health. *The American Psychologist*, *55*(1), 110–121. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11392855

Sandercock, G., Bromley, P., & Brodie, D. (2005). Effects of Exercise on Heart Rate Variability: Inferences from Meta-Analysis. *Medicine and Science in Sports and Exercise*, *37*(3), 433–439. doi:10.1249/01.MSS.0000155388.39002.9D

Sausen, K. P., Lovallo, W. R., Pincomb, G. A., & Wilson, M. F. (1992). Cardiovascular responses to occupational stress in male medical students: a paradigm for ambulatory monitoring studies. *Health Psychology*, *11*(1), 55–60. doi:10.1037/0278-6133.11.1.55

Schlotz, W., Kumsta, R., Layes, I., Entringer, S., Jones, A., & Wüst, S. (2008). Covariance between psychological and endocrine responses to pharmacological challenge and psychosocial stress: a question of timing. *Psychosomatic Medicine*, *70*, 787–796. doi:10.1097/PSY.0b013e3181810658

Schwartz, A. (2003). Toward a causal model of cardiovascular responses to stress and the development of cardiovascular disease. *Psychosomatic Medicine*, *65*(1), 22–35. doi:10.1097/01.PSY.0000046075.79922.61

Schwerdtfeger, A., Eberhardt, R., & Chmitorz, A. (2008). Gibt es einen Zusammenhang zwischen Bewegungsaktivität und psychischem Befinden im Alltag? *Zeitschrift Für Gesundheitspsychologie*, *16*(1), 2–11. doi:10.1026/0943-8149.16.1.2

Selye, H. (1936). A syndrome produced by diverse nocuous agents. *Nature*, *138*, 32.

Selye, H. (1946). The general adaptation syndrome and diseases of adaptation. *Journal of Clinical Endocrinology*, *6*, 117–73.

Sherman, D. K., Bunyan, D. P., Creswell, J. D., & Jaremka, L. M. (2009). Psychological vulnerability and stress: the effects of self-affirmation on sympathetic nervous system responses to naturalistic stressors. *Health Psychology*, *28*(5), 554–562. doi:10.1037/a0014663

Shiffman, S. (2007). Designing protocols for ecological momentary assessment. In A. A. Stone, S. Shiffman, A. A. Atienza, & L. Nebeling (Eds.), *The Science of Real-Time Data Capture: Self-Reports in Health Research* (pp. 27–53). New York: Oxford University Press.

Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological momentary assessment. *Annual Review of Clinical Psychology*, *4*, 1–32. doi:10.1146/annurev.clinpsy.3.022806.091415

Simonen, R. L., Rankinen, T., Pérusse, L., Leon, A. S., Skinner, J. S., Wilmore, J. H., … Bouchard, C. (2003). A dopamine D2 receptor gene polymorphism and physical activity in two family studies. *Physiology & Behavior*, *78*(4-5), 751–757. doi:10.1016/S0031-9384(03)00084-2

Sliwinski, M. J., Almeida, D. M., Smyth, J., & Stawski, R. S. (2009). Intraindividual change and variability in daily stress processes: findings from two measurement-burst diary studies. *Psychology and Aging*, *24*(4), 828–840. doi:10.1037/a0017925

Sloan, R., Shapiro, P., DeMeersman, R., Bagiella, E., Brondolo, E., McKinley, P., … Myers, M. (2011). Impact of aerobic training on cardiovascular reactivity to and recovery from challenge. *Psychosomatic Medicine*, *73*, 134–141. doi:10.1097/PSY.0b013e31820a1174

Sloan, R., Shapiro, P., DeMeersman, R. E., Bagiella, E., Brondolo, E. N., McKinley, P. S., … Myers, M. M. (2009). The effect of aerobic training and cardiac autonomic regulation in young adults. *American Journal of Public Health*, *99*(5), 921–928. doi:10.2105/AJPH.2007.133165

Sobocki, P., Jönsson, B., Angst, J., & Rehnberg, C. (2006). Cost of depression in Europe. *Journal of Mental Health Policy and Economics*, *9*(2), 87–98.

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. doi:10.1037/a0014953

Sothmann, M. (2006). The Cross-Stressor Adaptation Hypothesis and exercise training. In E. O. Acevedo & P. Ekkekakis (Eds.), *The Psychobiology of Physical Activity* (pp. 149–160). Champaign: Human Kinetics.

Sothmann, M., Buckworth, J., Claytor, R., Cox, R., White-Welkley, J., & Dishman, R. (1996). Exercise Training and the Cross-Stressor Adaptation Hypothesis. *Exercise and Sport Sciences Reviews:*, *24*, 267–287.

Sothmann, M., Hart, B. A., & Horn, T. S. (1991). Plasma catecholamine response to acute psychological stress in humans: relation to aerobic fitness and exercise training. *Medicine and Science in Sports and Exercise*, *23*(7), 860–867. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1921680

Spalding, T. W., Jeffers, L. S., Porges, S. W., & Hatfield, B. D. (2000). Vagal and cardiac reactivity to psychological stressors in trained and untrained men. *Medicine and Science in Sports and Exercise*, *32*(3), 581–591. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10730999

Spalding, T. W., Lyon, L. A., Steel, D. H., & Hatfield, B. D. (2004). Aerobic exercise training and cardiovascular reactivity to psychological stress in sedentary young normotensive men and women. *Psychophysiology*, *41*, 552–562. doi:10.1111/j.1469-8986.2004.00184.x

Spangler, G. (1997). Psychological and physiological responses during an exam and their relation to personality characteristics. *Psychoneuroendocrinology*, *22*(6), 423–441.

Steffen, P. R., Sherwood, A., Gullette, E. C., Georgiades, A., Hinderliter, A., & Blumenthal, J. (2001). Effects of exercise and weight loss on blood pressure during daily life. *Medicine and Science in Sports and Exercise*, *33*(10), 1635–1640.

Steinberg, H., Nicholls, B. R., Sykes, E. A., LeBoutillier, N., Ramlakhan, N., Moss, T. P., & Dewey, A. (1998). Weekly Exercise Consistently Reinstates Positive Mood. *European Psychologist*, *3*(4), 271–280. doi:10.1027/1016-9040.3.4.271

Steptoe, A., Kimbell, J., & Basford, P. (1998). Exercise and the experience and appraisal of daily stressors: a naturalistic study. *Journal of Behavioral Medicine*, *21*(4), 363–374. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9789166

Steyer, R., Schwenkmezger, P., & Eid, M. (1997). *The Multidimensional Mood Questionnaire (MDMQ)*. Göttingen: Hogrefe.

Stone, A. A., Ree, B., & Neale, J. (1987). Changes in daily event frequency precede episodes of physical symptoms. *Journal of Human Stress*, *13*, 70–74.

Stone, A. A., Smyth, J. M., Pickering, T., & Schwartz, J. (1996). Daily Mood Variability: Form of Diurnal Patterns and Determinants of Diurnal Patterns. *Journal of Applied Social Psychology*, *26*, 1286–1305. doi:10.1111/j.1559-1816.1996.tb01781.x

Stults-Kolehmainen, M. A. (2013). The interplay between stress and physical activity in the prevention and treatment of cardiovascular disease. *Frontiers in Physiology*, *4*, 27–30. doi:10.3389/fphys.2013.00346

Stults-Kolehmainen, M. A., & Sinha, R. (2014). The effects of stress on physical activity and exercise. *Sports Medicine*, *44*(1), 81–121. doi:10.1007/s40279-013-0090-5

Tamashiro, K. L., Sakai, R. R., Shively, C. a, Karatsoreos, I. N., & Reagan, L. P. (2011). Chronic stress, metabolism, and metabolic syndrome. *Stress*, *14*(5), 468–474. doi:10.3109/10253890.2011.606341

Task Force. (1996). Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Circulation*, *93*(5), 1043–1065. doi:10.1161/01.cir.93.5.1043

Tharion, E., Parthasarathy, S., & Neelakantan, N. (2009). Short-term heart rate variability measures in students during examinations. *National Medical Journal of India*, *22*(2), 63–66.

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. doi:10.1023/A:1009574428627

Trull, T., & Ebner-Priemer, U. W. (2013). Ambulatory Assessment. *Annual Review of Clinical Psychology*, *9*, 151–176. doi:10.1146/annurev-clinpsy-050212-185510

Tsatsoulis, A., & Fountoulakis, S. (2006). The protective role of exercise on stress system dysregulation and comorbidities. *Annals of the New York Academy of Sciences*, *1083*, 196–213. doi:10.1196/annals.1367.020

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), 364–72. doi:10.1152/japplphysiol.00751.2002

Tuomainen, P., Peuhkurinen, K., Kettunen, R., & Rauramaa, R. (2005). Regular physical exercise, heart rate variability and turbulence in a 6-year randomized controlled trial in middle-aged men: The DNASCO study. *Life Sciences*, *77*(21), 2723–2734. doi:10.1016/j.lfs.2005.05.023

Uusitalo, A., Laitinen, T., Väisänen, S. B., Länsimies, E., & Rauramaa, R. (2004). Physical training and heart rate and blood pressure variability: a 5-yr randomized trial. *American Journal of Physiology. Heart and Circulatory Physiology*, *286*(5), H1821–H1826. doi:10.1152/ajpheart.00600.2003

Van Eck, M., Berkhof, H., Nicolson, N., & Sulon, J. (1996). The effects of perceived stress, traits, mood states, and stressful daily events on salivary cortisol. *Psychosomatic Medicine*, *58*, 447–458. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8902896

Van Eck, M., Nicolson, N. A., & Berkhof, J. (1998). Effects of stressful daily events on mood states: relationship to global perceived stress. *Journal of Personality and Social Psychology*, *75*(6), 1572–1585. doi:10.1037/0022-3514.75.6.1572

Van Someren, E. J. W., Lazeron, R. H. C., Vonk, B. F. M., Mirmiran, M., & Swaab, D. F. (1996). Gravitational artefact in frequency spectra of movement acceleration: Implications for actigraphy in young and elderly subjects. *Journal of Neuroscience Methods*, *65*(1), 55–62. doi:10.1016/0165-0270(95)00146-8

Vesterinen, V., Häkkinen, K., Hynynen, E., Mikkola, J., Hokka, L., & Nummela, A. (2013). Heart rate variability in prediction of individual adaptation to endurance training in recreational endurance runners. *Scandinavian Journal of Medicine and Science in Sports*, *23*(2), 171–180. doi:10.1111/j.1600-0838.2011.01365.x

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. doi:10.1161/01.HYP.35.4.880

Warburton, D. E. R., Katzmarzyk, P. T., Rhodes, R. E., & Shephard, R. J. (2007). Evidence-informed physical activity guidelines for Canadian adults. *Applied Physiology, Nutrition, and Metabolism*, *32*, 16–68. doi:10.1139/H07-123

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity : the evidence. *Canadian Medical Association Journal*, *174*(6).

Warren, J., Ekelund, U., Besson, H., Mezzani, A., Geladas, N., & Vanhees, L. (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 Rehabilitation*, *17*, 127–139. doi:10.1097/HJR.0b013e32832ed875

Warren, T., Barry, V., Hooker, S. P., Sui, X., Church, T. S., & Blair, S. (2010). Sedentary behaviors increase risk of cardiovascular disease mortality in men. *Medicine and Science in Sport and Exercise*, *42*(5), 879–885. doi:10.1249/MSS.0b013e3181c3aa7e.Sedentary

Watson, D., Clark, L. a, & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063–1070. doi:10.1037/0022-3514.54.6.1063

Weekes, N., Lewis, R., Patel, F., Garrison-Jakel, J., Berger, D. E., & Lupien, S. J. (2006). Examination stress as an ecological inducer of cortisol and psychological responses to stress in undergraduate students. *Stress*, *9*(4), 199–206. doi:10.1080/10253890601029751

Weekes, N. Y., Lewis, R. S., Goto, S. G., Garrison-Jakel, J., Patel, F., & Lupien, S. (2008). The effect of an environmental stressor on gender differences on the awakening cortisol response. *Psychoneuroendocrinology*, *33*(6), 766–772. doi:10.1016/j.psyneuen.2008.03.003

Wichers, M., Peeters, F., Rutten, B. P. F., Jacobs, N., Derom, C., Thiery, E., … van Os, J. (2012). A time-lagged momentary assessment study on daily life physical activity and affect. *Health Psychology*, *31*(2), 135–144. doi:10.1037/a0025688

Wilhelm, H., Grossman, P., & Müller, M. I. (2012). Bridging the gap between the laboratory and the real world: Integrative ambulatory psychophysiology. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 210–234). New York: The Guilford Press.

Wilhelm, P., & Schoebi, D. (2007). Assessing Mood in Daily Life. *European Journal of Psychological Assessment*, *23*(4), 258–267. doi:10.1027/1015-5759.23.4.258

Wipfli, B., Rethorst, C., & Landers, D. (2008). The anxiolytic effects of exercise: a meta-analysis of randomized trials and dose-response analysis. *Journal of Sport & Exercise Psychology*, *30*(4), 392–410.

Wittels, P., Rosenmayr, G., Bischof, B., Hartter, E., & Haber, P. (1994). Aerobic fitness and sympatho-adrenal response to short-term psycho-emotional stress under field conditions. *European Journal of Applied Physiology and Occupational Physiology*, *68*(5), 418–424. doi:10.1007/BF00843739

Youngstedt, S. D. (2005). Effects of exercise on sleep. *Clinics in Sports Medicine*, *24*(2), 355–365. doi:10.1016/j.csm.2004.12.003

Yusuf, P. S., Hawken, S., Ôunpuu, S., Dans, T., Avezum, A., Lanas, F., … Lisheng, L. (2004). Effect of potentially modifiable risk factors associated with myocardial infarction in 52 countries (the INTERHEART study): Case-control study. *Lancet*, *364*(9438), 937–952. doi:10.1016/S0140-6736(04)17018-9

Zanstra, Y. J., & Johnston, D. W. (2011). Cardiovascular reactivity in real life settings: measurement, mechanisms and meaning. *Biological Psychology*, *86*(2), 98–105. doi:10.1016/j.biopsycho.2010.05.002

Zautra, A. J., Affleck, G. G., Tennen, H., Reich, J. W., & Davis, M. C. (2005). Dynamic approaches to emotions and stress in everyday life: Bolger and Zuckerman reloaded with positive as well as negative affects. *Journal of Personality*, *73*(6), 1511–1538. doi:10.1111/j.0022-3506.2005.00357.x

Figures

Tables

Appendix I

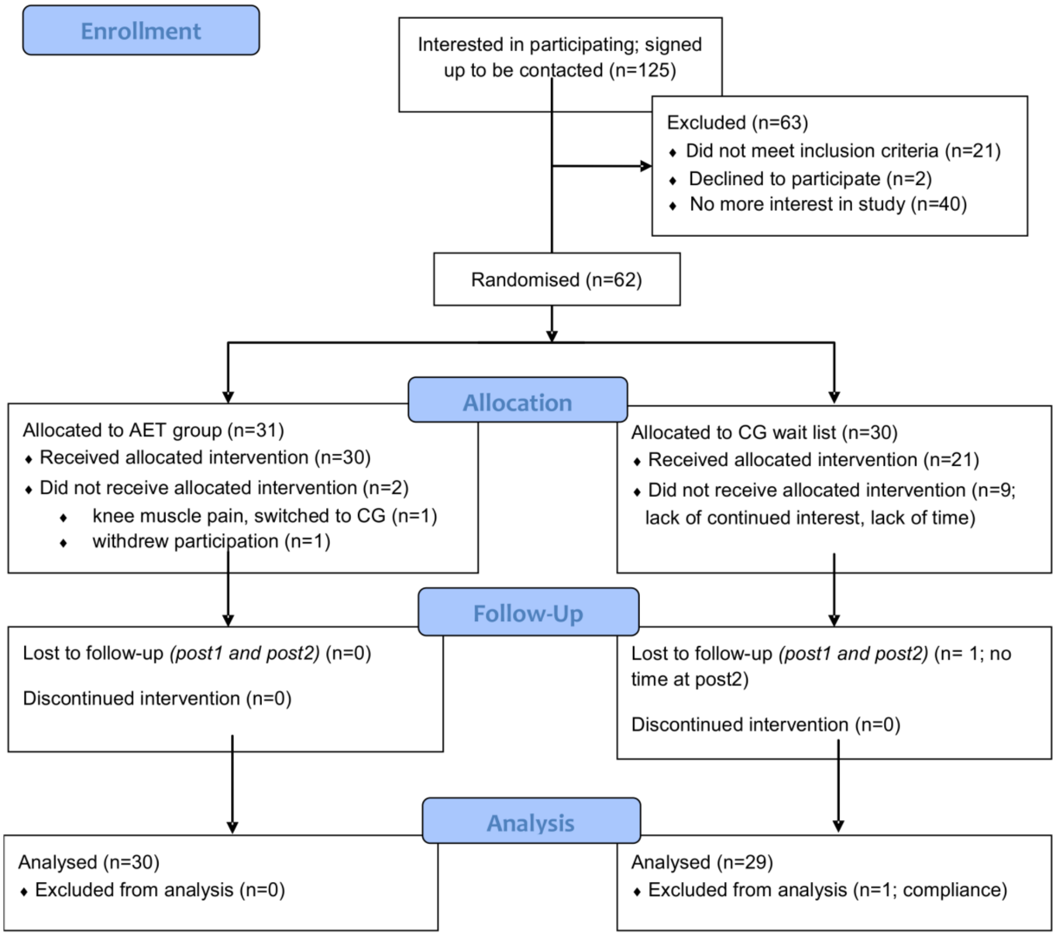

Figure A1 (*Chapter 3*): Participant Flow Diagram of the randomized, controlled trial

Appendix II

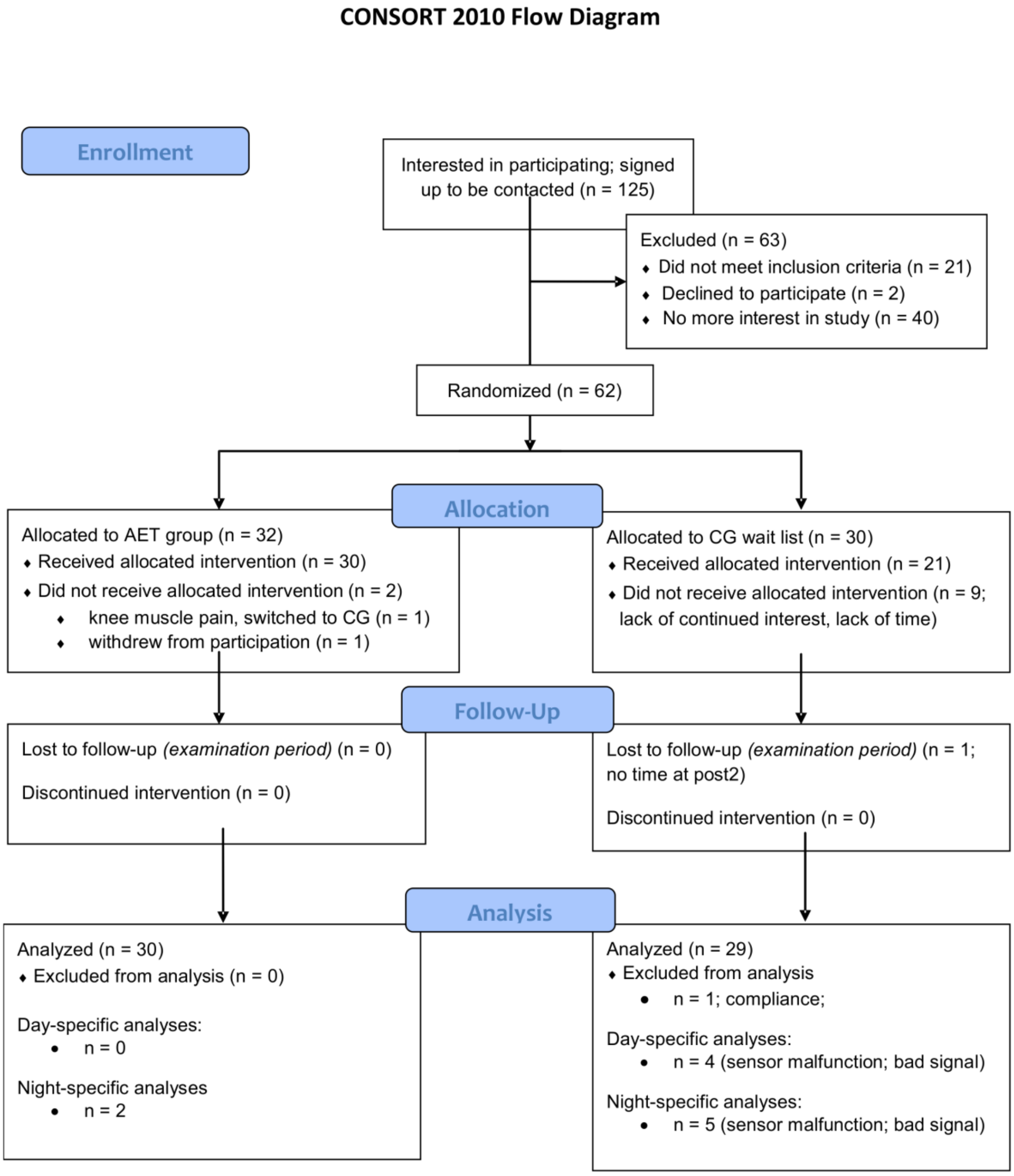

Figure B1 (*Chapter 4*): Participant Flow Diagram of the randomized, controlled trial

Publications

Peer-Reviewed Research Articles

1	2015	von Haaren, B., Ottenbacher, J., Muenz, J., Neumann, R., Boes, K., & Ebner-Priemer, U. (under Review). Does a 20-week aerobic exercise training increase our capabilities to buffer real-life stressors? A randomized, controlled trial using Ambulatory Assessment. *European Journal of Applied Physiology*.
2	2015	von Haaren, B., Haertel, S., Stumpp, J., Hey, S., & Ebner-Priemer, U.W. (2015). Reduced emotional stress reactivity to a real-Life academic examination stressor in students participating in a 20-Week aerobic exercise training: A randomized, controlled trial using Ambulatory Assessment. *Psychology of Sport and Exercise, 20,* 67-75. *10.1016/j.psychsport. 2015.04.004.*
3	2014	Shammas, L., von Haaren, B., Kunzler, A., Zentek, T. & Rashid, A. (2014). Detection of parameters to quantify neurobehavioral alteration in Multiple Sclerosis based on daily life physical activity and gait using Ambulatory assessment. *Zeitschrift für Neuropsychologie, 25 (4). 10.1024/1016-264X/a000141.*
4	2014	Hey, S., Anastasopoulou, P. & von Haaren, B. (2014). Erfassung körperlicher Aktivität mittels Akzelerometrie - Möglichkeiten und Grenzen aus technischer Sicht. *Bewegungstherapie & Gesundheitssport, 30* (2), 73-78. 10-1055/s-0033-1361577.
5	2014	Hey, S., Anastasopoulou, P. & von Haaren, B. (2014). Erfassung körperlicher Aktivität mittels Akzelerometrie - Möglichkeiten und Grenzen aus technischer Sicht. *Aktuelle Rheumatologie, 39* , 1-5. 10.1055/s-0034-1387721.
6	2014	Shammas, L., Zentek, T., von Haaren, B., Schlesinger, S., Hey, S. & Rashid, A. (2014). Home-based system for physical activity monitoring in patients with multiple sclerosis (Pilot study). *Biomedical Engineering online, 13*:10. 10.1186/1475-925X-13-10.
7	2013	von Haaren, B., Loeffler, S.N., Haertel, S., Anastasopoulou, P., Stumpp, J., Hey, S. & Boes, K. (2013) Characteristics of the activity-affect association in inactive people: an ambulatory assessment study in daily life. *Frontiers in Psychology, 4*, 163. 10.3389/fpsyg.2013.00163.
8	2013	Walter, K., von Haaren, B., Löffler, S., Härtel, S., Jansen, C.P., Werner, C., Stumpp, J., Bös, K. & Hey, S. (2013). Acute and medium term effects of a 10-week running intervention on mood state in apprentices. *Frontiers in Psychology. 4*, 411. 10.3389/fpsyg.2013.00411.
9	2011	von Haaren, B., Härtel, S., Seidel, I., Schlenker, L. & Bös, K. Die Validität des 6-Minuten-Laufs und 20m Shuttle Runs bei 9- bis 11-jährigen Kindern. (2011). *Deutsche Zeitschrift für Sportmedizin, 62* (11), 351-355.

Eidesstattliche Erklärung

Ich versichere, dass die vorliegende Dissertation mit dem Titel „Effects of Aerobic Exercise Training on Stress Reactivity in Every-Day Life“ selbständig verfasst wurde und keine anderen als die angegebenen Hilfsmittel benutzt sowie die Stellen der Arbeit, die anderen Werken dem Wortlaut oder dem Sinn nach entnommen sind, durch Angabe der Quellen kenntlich gemacht wurden. Des Weiteren versichere ich, dass ich die Satzung des Karlsruher Instituts für Technologie (KIT) [ehemals Satzung der Universität Karlsruhe (TH)] zur Sicherung guter wissenschaftlicher Praxis beachtet habe. Diese Arbeit wurde nicht bereits anderweitig als Prüfungsarbeit verwendet.

....

Birte von Haaren

Karlsruhe, den 30.4.2015