D I S S E R T A T I O N

Exercise and sleep in female pupils:
effects between two types of exercise interventions on autonomic sleep quality
by heart rate variability

submitted by

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Declaration

I hereby declare that this thesis is my own original work and that I have fully acknowledged by name all of those individuals and organizations that have contributed to the research for this thesis. Due acknowledgement has been made in the text to all other material used. Throughout this thesis and in all related publications I followed the guidelines of "Good Scientific Practice".

Graz,

Dedication

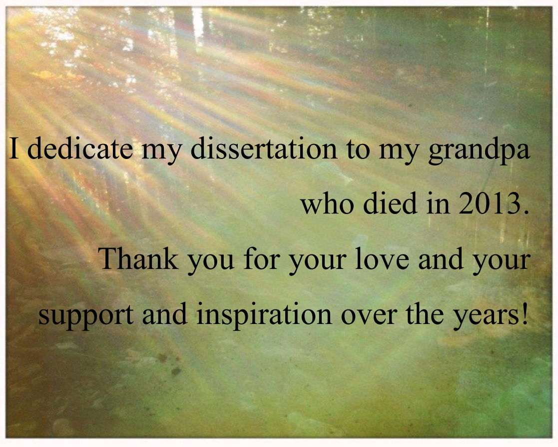

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Table of Contents

ABSTRACT: DEUTSCH ... 6
ABSTRACT: ENGLISH ... 8
1 Introduction ... 10
1.1 Physical activity and health in children and adolescents ... 10
1.1.1 Defining physical activity ... 10
1.1.1.1 Components of dose ... 11
1.1.1.2 Types of Physical Activity ... 17
1.1.2 Effects of cardiorespiratory activity in children and adolescents ... 19
1.1.2.1 Short-term physiological response to cardiorespiratory exercise ... 19
1.1.2.2 Health response to cardiorespiratory exercise from childhood to adulthood . 23
1.1.3 Current physical activity recommendation for children and adolescents ... 30
1.2 Chronobiology and its circadian rhythms ... 33
1.2.1 Circadian rhythms - an introduction ... 33
1.2.2 Sleep ... 37
1.2.2.1 Definition of sleep and its stages ... 37
1.2.2.2 Physiological changes in sleep ... 40
1.2.2.3 The relationssship between cardiac autonomic modulation and HRV ... 41
1.2.2.4 Functions of sleep ... 45
1.2.3 Sleep during adolescence ... 47
1.2.3.1 Sleep problems during adolescence ... 49
1.3 Effects of Physical Activity on sleep quality ... 51
1.4 Aims and research questions ... 58
2 Methods and Hypothesis ... 60
2.1 Participants ... 60
2.2 Study Design ... 64
2.3 Measurements ... 66
2.3.1 Time of Measurements ... 66
2.3.2 Physiological Measures ... 66
2.3.3 Sport Scientific Measure ... 73
2.3.4 Psychological Measure ... 74
2.4 Intervention ... 79

2.5 Statistical analysis 80
2.6 Hypotheses 81
3 Results 83
3.1 Physiological parameters 83
3.1.1 Impact of physical activity on autonomic modulation during sleep 83
3.1.2 Autonomic sleep quality 89
3.1.2.1 Different impacts of both training interventions on autonomic sleep quality 89
3.1.2.2 Development of the autonomic sleep quality by SQidx 92
3.1.2.3 Development of the sleep quality by sleeping questionnaires 94
3.1.3 ON effect of the training during the interims between pre- to int. period 99
3.2 Sport scientific parameters 108
3.2.1 Heart rate (HR) 108
3.2.2 Aerobic capacity 109
3.2.3 Questionnaire about Physical Activity (IPAQ) 111
3.3 Psychological Parameters 113
3.3.1 Erholungs-Belastungs-Fragebogen (EBF) 113
3.3.2 Befindlichkeitsskalierung durch Kategorien und Eigenschaftswörter (BSKE) 115
3.3.3 Mehrdimensionale Körperliche Symptomliste (MKSL) 117
4 Discussion 118
4.1 Significant impact of physical activity on autonomic modulation during sleep 119
4.2 Autonomic sleep quality 120
4.2.1 Different impacts of both training interventions on autonomic sleep quality 120
4.2.2 ON-effect of the sport interventions during sleep 122
4.3 ON effects during circadian variations 123
4.4 The influence of physical activity on cardio-respiratory fitness 124
4.4.1 Significant increase of the fitness level after a short-term intervention 124
4.4.2 Individual response to the interventions 125
4.5 Accordance of psychological to physiological outcomes concerning sleep 126
4.6 Overview of the hypothesis and the results 127
References 128

ABSTRACT: DEUTSCH

Bewegung und Schlaf bei Schülerinnen: Zusammenhang zwischen zwei verschiedenen Bewegungsinterventionen und der autonomen Schlafqualität erfasst mittels Herzratenvariabilität

Hintergrund: Chronobiologische Faktoren mit zirkadianer Rhythmik spielen in der Schlafregulation eine wichtige Rolle (Moser et al. 2006; Moser et al. 2008). Schlaf ist ein hoch komplexer und physiologisch aktiver Zustand, der sich durch neuronale Aktivierung und autonome Modulation charakterisiert. Die Herzrate, beeinflusst von sympathischer und vagaler Wechselwirkung, ist eine wichtige kardiovaskuläre Stellgröße, die im zeitlichen Verlauf als Herzratenvariabilität (HRV) messbar wird. Die Erfassung von HRV- Kennwerten während des Schlafes ist eine non-invasive wissenschaftlich fundierte Methode (Task Force, 1996), um Auskunft über die autonome Regulation und somit über den autonomen nocturnen Erholungszustand (Passos et al. 2011) zu geben. Da ein unmittelbarer Zusammenhang zwischen autonomer Schlaferholung und Gesundheit besteht, ist es wichtig zu wissen, wie dieser optimiert werden kann. Ergebnisse aktueller Studien (Driver& Taylor 2000; Myllymaki et al. 2011; Passos et al. 2011) verweisen auf die positive Wirkung von Sport auf die Schlafstruktur, die beispielsweise durch höhere Schlafeffizienz (hohe vagale Aktivierung), Steigerung der Gesamtschlafzeit und Kürzung der REM- Phasen charakterisiert werden kann. Die Notwendigkeit im Jugendbereich anzusetzen, ergibt sich daraus, dass Schlafstörungen in dieser Altersklasse immer häufiger auftreten und eine Basis für Entwicklungsdefizite schaffen.
Ziel: Ziel dieser Studie war es, den Einfluss zweier Bewegungsinterventionen (Lauftraining vs. Koordinationstraining mit höherer Intensität) auf die autonome Schlaferholung bei Schülerinnen mittels HRV zu untersuchen. In weiterer Folge soll überprüft werden, ob sich die Wirkungsweise der beiden Interventionen auf die autonome Modulation unterscheidet.
Studiendesign: Akquiriert wurden 31 gesunde Schülerinnen aus dem Privatgymnasium Sacrè Coeur, Graz im Alter zwischen 14 und 16 Jahren, für die Analysen wurden die Daten von 26 Schülerinnen herangezogen. Die Interventionsstudie dauerte insgesamt acht Wochen und lässt sich in eine zweiwöchige PRE, vierwöchige INTERVENTIONS und zweiwöchige POST-Phase untergliedern. Fragebögen in Form eines Messtagebuches wurden wöchentlich ausgefüllt und 25h-HRV Messungen wurden nach einer Testmessung in W1 fünf Mal durchgeführt: 1x in der PRE-Phase (W2), 2x in der INTERVENTIONS-Phase (W3, W5), 2x

in der POST-Phase (W7, W8). Ein „shuttle-run“- Test erfolgte in der W2 und W7, um den Fortschritt der Fitness aller Schülerinnen zu dokumentieren. Während der Interventionsphase nahmen die Schülerinnen 3x wöchentlich für 30 Minuten an der Lauf- bzw. Koordinationsintervention teil. Das Lauftraining wurde zeitgleich mit dem Koordinationstraining (Aerobic) mit höherer Intensität durchgeführt.

Ergebnisse: Beide Gruppen konnten ihre Fitness, gemessen durch den shuttle run (p=.001) steigern, jedoch konnte eine signifikante Reduktion der Gesamtherzrate während des Tages (p=.040) und während des Schlafes (p=.045) ausschließlich in der Laufgruppe beobachtet werden. Das Verhältnis von LF und HF, ausgedrückt durch den VQ zeigte eine signifikante Wechselwirkung (p=.042), das die unterschiedliche Trainingskompensation beider Gruppen unterstreicht. Das Koordinationstraining führte zu einer Abnahme des VQs; dies bedeutet ein hohes Maß an Entspannung während des Schlafes, nachdem die Trainingsintervention begonnen hatte. Weniger Entspannung erreichte die Laufgruppe, die ein hohes Aktivitätspotenzial in der ersten Woche des Trainings ausschüttete. Diese unterschiedliche Entwicklung stimmt mit den LFhf Parameter überein (Wechselwirkung: p=.049), der den höchsten Wert in der Laufgruppe während der ersten Interventionswoche zeigte; auch dies bedeutet unruhigen Schlaf.

Conclusio: In dieser Studie konnte gezeigt werden, dass verschiedene Trainingsinterventionen mit gleicher Dauer und Intensität die autonome Modulation während der Nacht unterschiedlich beeinflussten. Schülerinnen, die am Koordinationstraining teilnahmen, hatten eine höhere autonome Erholung während des Schlafs als Schülerinnen des Lauftrainings. Aktuelle Literatur zeigt, dass sich nach dem Training eine höhere Herzrate und erniedrigte HRV-Kennwerte während der Nacht einstellen (Hynynen et al. 2010), jedoch ist der Stand der Wissenschaft über nächtliche HRV-Parameter nach dem Training noch lange nicht vergleichbar mit dem Forschungsstand des Wachzustandes. Studien mit Jugendlichen zur autonomen Erholung während der Nacht sind kaum vorhanden. Forschungsbedarf in Bezug auf den Zusammenhang zwischen Sport und Schlaf ist durchaus gegeben.

ABSTRACT: ENGLISH

Exercise and sleep in female pupils: effects between two types of exercise interventions on autonomic sleep quality by heart rate variability

Background: Chronobiology, with its circadian rhythmicity, plays an important role in sleep regulation (Moser et al. 2006; Moser et al. 2008). Sleep is a complex and physiological highly active state characterized by neuronal activation and autonomic modulation. The heart rate influenced by sympathetic and parasympathetic outflow is an important cardiovascular parameter that becomes quantifiable as heart rate variability (HRV) is measured over time. The measurement of HRV-indices during sleep is a non-invasive method for getting information about the autonomic regulation with its nocturne recovery. As there is a relation between autonomic sleep recovery and health, it would be important to know how to optimize this coherence. Current literature (Driver& Taylor 2000; Myllymaki et al. 2011; Passos et al. 2011) demonstrates the positive influence of physical activity on the sleeping structure characterized by higher sleep efficacy (higher vagal activation), higher total sleep time and reduction of REM cycles. It is relevant to focus on adolescents as sleeping disorders that are responsible for developmental deficits occur more often during this crucial period.

Purpose: The aim of this study was to examine the impact between two types of intervention (vigorous-intensity endurance training vs. coordination) on the autonomic sleep recovery in female pupils by HRV and to analyse possibly different influences on the autonomic modulation.

Study Design: 31 healthy female pupils from the private school Sacrè Coeur, Graz aged between 14 and 16 years were included in the study, 26 pupils were chosen for analysis. The intervention study lasted eight weeks and was split up into PRE (2 weeks), INTERVENTION (4 weeks) and POST (2 weeks) periods. Questionnaires as measure diaries were collected once a week, 25-hour HRV measurements were conducted 5 times after a test measurement: 1x in the PRE (w2), 2x in the INTERVENTION (w3;w5), and 2x in the POST (w7; w8) period. The “shuttle run” was conducted during w2 and w7 to compare the fitness of the pupils before and after the intervention. During the INTERVENTION period, the pupils took part in a 30-minute jogging or coordination training 3 times a week. The jogging training was simultaneously carried out with the coordinative training (aerobic) with vigorous intensity.

Results: Both groups increased their level of fitness, measured by the shuttle run (p=.001), although a significant decrease of the HR during the day (p=.040) and during sleep (p=.045)

could only be observed in the jogging group. The ratio between LF and HF, seen in the VQ, revealed a significant interaction (p=.042), pointing out the different compensation of both groups. The coordinative training led to a decrease in VQ values, indicating a high potential of relaxation during sleep after the training had begun. Less nocturne recovery was achieved by the jogging group showing a high level of activation in the first week of training. This divergent development agrees with values of LFhf (interaction: p= .049) that showed the highest level in the jogging group during the first week of intervention, indicating restless sleep.

Conclusion: This study showed that both interventions with the same intensity and duration influenced the autonomic modulation during sleep in a different way. The coordinative group showed a higher autonomic recovery during sleep than the jogging group. In current literature (Hynynen et al. 2010), it is known that after training, a higher heart rate and lower HRV can be observed during sleep, but the knowledge about physical activity and nocturnal HRV parameters after the training cannot be compared to the scientific level during wakefulness. Even more, studies with children or adolescents on autonomic recovery during the night are still lacking. For that reason, there is evidence to focus on the relationship between physical activity and sports.

1 Introduction

The introduction offers a scientific overview about the relationship between health, physical activity and sleep and gives a theoretical input on the two major fields, physical activity and sleep. The first part introduces terms and definitions around physical activity and explains physiological adaptions of the body and health benefits as response on cardiorespiratory activity. Following the Physical Activity Recommendations in order to sustain or improve health the effectiveness of school interventions is demonstrated. The second part starts with a short introduction on circadian rhythmicity with its main component, the sleep-wake cycle. Definitions, physiology with its autonomic modulation and the functions of sleep should give a theoretical insight to better understand the HRV assessment during night. After the information on sleep structure and sleep problems during adolescence, the impact of physical activity on sleep quality completes the theoretical input and leads to the research questions.

1.1 Physical activity and health in children and adolescents

This chapter provides definitions of major terms around physical activity in current sport scientific research. After the overview of types (dose, intensity, volume) and the art of physical activity prescriptions the main impacts of physical activity on the bodily functioning are enrolled, subdivided into short-term and long-term response. The short review of long term benefits of physical activity in children and adolescents represents the background for the physical activity recommendations. The efficacy of school- interventions programs following those recommendations is proofed.

1.1.1 Defining physical activity

This sub-chapter provides definitions of the major terms used in scientific literature over the past years. To better understand the association between health aspects and physical activity it is important to define and explain the termini around physical activity.

(Caspersen, Powell & Christenson 1985) were one of the prior experts in defining terminologies of physical activity (PA). They defined physical activity as "any bodily movement produced by skeletal muscles that results in energy expenditure" (Caspersen,

Powell & Christenson 1985, p.126). They also stated that physical activity can be categorized in different ways, ranging from physical activity during sleep, work and leisure. Leisure time activity may include sport performance, exercise bouts, house hold tasks and other activities.

(Howley ET 2001) readopted the classification and divided the terminus PA into "leisure time", including activities during free time and "occupational" PA, associated with the performance of a job. Leisure time activities like walking, dancing, gardening may be part of physical activity sessions resulting in substantial energy expenditure.

(Bouchard, Blair & Haskell 2012) carried the sub classifications (leisure, work) of PA on and added that they are strongly depended of personal needs and interests. They classified "exercise" as part of leisure-time activity, usually being performed over a certain period with a predefined objective like improved fitness, physical performance or health. Exercise depends on mode, intensity, frequency and duration (Bouchard, Blair & Haskell 2012).

The U.S. Department of Health and Human Services (2008), one of the worldwide leading panels of research on physical activity also defined exercise as a subcategory of leisure time activity with the aim of maintenance or improvement of health and physical performance(U.S. Department of Health and Human Services. 2008, Part C).

The statement to these definitions is that physical activity requires bodily movements leading to higher energy expenditure and happens due to activities during leisure or working time. "Exercise" as a subcategory of leisure time activity is structured and planned with a predefined aim.

1.1.1.1 Components of dose

The dose of physical activity is determined by frequency, duration, intensity and mode. The following descriptions are derived from different sources such as (Howley ET 2001, Bouchard, Blair & Haskell 2012, American College of Sports Medicine 2000, Bouchard, Rankinen 2001, Titze 2003).

Frequency

Frequency can be seen as the number of sessions per day, week or month practicing PA. Literature typically refers to the undertaken number of sessions per week.

Duration

Duration often refers to the duration of a physical activity session and is mostly expressed in minutes or hours per session.

Mode

The mode of exercise gives information about the intensity of activity, the involved muscle groups and the temporal pattern of activity. In general, distinctions are made between resistance and endurance training.

Intensity

Intensity is a determining factor in defining physical activity and is expressed in absolute or relative values in current literature (Howley ET 2001, U.S. Department of Health and Human Services. 2008, Bouchard, Rankinen 2001).

Absolute intensity expresses the required work for an activity, independent of someone´s physiologic capacity. The rate of energy expenditure is taken into consideration for the absolute intensity of aerobic activity, expressed in different ways: oxygen uptake ($L \cdot min^{-1}$), kilocalories per minutes, METs or speed of the activity (miles per hour/ kilometres per hour). For resistance training the absolute intensity of weight or force values is defined in pounds or kilograms (U.S. Department of Health and Human Services. 2008, Part D3).

Relative Intensity is defined as the intensity relative to the fitness. It means that persons with a different sportive background, with regard to maximal heart rate, heart rate reserve and aerobic capacity respond in markedly diverse ways to an exercise session at a fixed absolute intensity. For example, an exercise intensity of 9 METs may require a minimal effort for one person, but a maximal strain for the other. "The relative intensity of aerobic activity has been described in terms of percentages of maximal oxygen uptake (VO_2 max), oxygen uptake reserve (VO_2R), heart rate reserve (HRR) and maximal heart rate (HR max)" (Howley ET 2001, p.366).

Determinations of intensity

Metabolic equivalent (MET)

The metabolic equivalent (MET), is a unit for describing the energy expenditure, one MET representing the expended energy at rest. MET is equal to resting oxygen uptake (VO_2) that is approximately 3.5 $ml.kg^{-1}.min^{-1}$ or 1 $kcal.kg^{-1}.h^{-1}$ (Howley ET 2001). In general METs are calculated from the ratio of the expended energy rate during activity to the energy at rest (Haskell et al. 2007). It means that a 3 MET activity requires three times more energy than at rest. Calculating a 3 MET activity for a 30 minutes session would mean an energy expenditure of 3x30= 90 MET-minutes. Light- intensity is described at a level of 1-3 METs, moderate intensity is defined as 3 - 5,9 METs and vigorous intensity starts at 6 METs (U.S. Department of Health and Human Services 2008, Appendix 1). (Ainsworth et al. 2011) have developed a compendium to ensure the comparability and to quantify the energy expenditure of different physical activities. This compendium is widely used in scientific research and has become state of the art.

Maximal oxygen uptake (VO_2 max)

Oxygen uptake by the lungs is increasing, when dynamic exercise has been started. After the second minute, oxygen uptake remains relatively stable (steady state) undertaking each level of intensity. The *maximal oxygen uptake* (VO_2 max) is the greatest amount of oxygen a person can use while doing physical activity involving a large part of total muscle mass. From the physiological point of view the air intake into the lungs ends in cellular oxidative phosphorylation (Rowland 2007). It means that the oxygen utilisation is limited VO_2 max represents the amount of oxygen transported and used in cellular metabolism and is convenient to express oxygen uptake in sitting and resting requirements (Fletcher GF et al. 1990, Fletcher et al. 2001). Absolute values are expressed in liters per minute (L.min), relative values additionally consider the body weight ($ml.kg^{-1}.min^{-1}$). Figure 1 shows normative VO_2max values of children and adolescents from actual studies with a great difference between girls and boys. The maximal oxygen uptake predicts the cardiovascular fitness indicating the functional capacity of the myriad components in the oxygen delivery chain. High values reflect a good cardiorespiratory power and cardiovascular endurance. Figure 2 shows the classification of relative VO_2 max values into excellent to very poor trained

females, depending from the age. In scientific research it is a common method to express intensity of exercise sessions as a percentage of VO_2 max (Howley ET 2001).

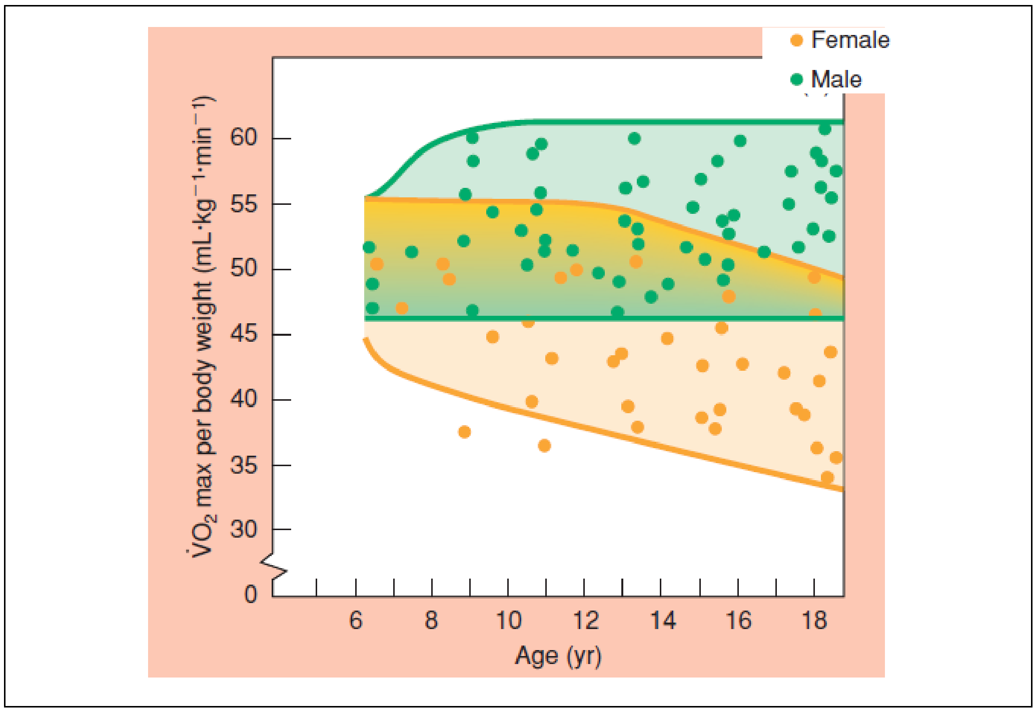


Figure 1: Distribution of VO_{2max} (mL.kg^{-1}.min^{-1}) values in girls and boys aged between 6-18 years. The dots represent mean values from actual studies, adapted from (Plowman, Smith 2008, p.367)

This figure demonstrates that the distribution of relative VO_{2max} values remains relative constant for boys, but decreases in girls at the onset of adolescence. Although the tendency for decreased values appears there is nevertheless an overlap for VO_{2max} for boys and girls indicating a large variability of relative maximal oxygen uptake among children and adolescents (Plowman, Smith 2008).

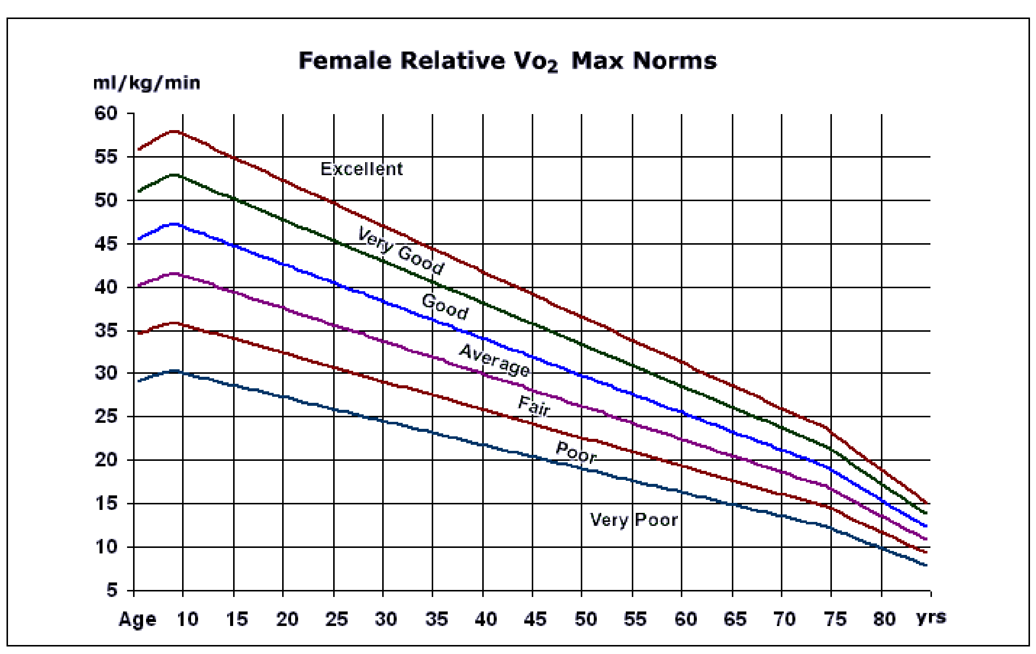


Figure 2: Classification of relative $VO_{2\ max}$ values of females aged between 10-80 years into excellent to very poor trained, adopted from (Shvartz, Reibold 1990) in http://www.aminoz.com.au/beep-test-calculator-shuttle-calc-8.html

This figure shows relative VO_{2max} values on the y- axis with regard to the age on the x- axis: it means that a 15- year old girl with values from 40 to 45 (ml/kg/min) is classified as average trained. Values under 27 (ml/kg/min) are very poor and values over 55 (ml/kg/min) are excellent.

Maximum heart rate (HR max)

The maximum heart rate (HR_{max}) is the highest heart rate peak during physical activity and is one of the most commonly used values in clinical medicine and physiology. Exercise intensity can be expressed in % of HR_{max} (Tanaka, Monahan & Seals 2001) as the heart rate increases linearly with VO_2 (Fletcher GF et al. 1990). Due to this linear relationship it is possible to use a percentage of HR *max* as an estimate of %VO_2 *max* (Howley ET 2001). Maximal heart rate can be investigated by maximal exercise testing or may also be predicted from age with one of the published equations: 220-age (American College of Sports Medicine 2000, p.117).

The *heart rate reserve* (HRR) is calculated by subtracting resting HR from maximal heart rate and is often taken to gauge exercise intensity. The same goes with *maximum oxygen reserve*

(VO_2R): it is calculated from the difference between resting and maximum VO_2 (Howley ET 2001).

The first classification of exercise intensity was established by the ACSM {{237 American College of Sports Medicine 2000}}, later on modified by (Howley ET 2001). Table 1 shows the different possibilities to determine the intensity of endurance training.

Table 1: Classification of exercise intensity in $\%HR_{max}$, $\%VO_{2\,max}$ and METs in healthy adults, adapted from (Howley ET 2001, p.367)

		VO_2 *max* = 12 METs		VO_2 *max* =8 METs		VO_2 *max* = 5 METs	
Intensity	% HR *max*	METs	$\%VO_2$ *max*	METs	$\%VO_2$ *max*	METs	$\%VO_2$ *max*
very light	<50	<3.2	<27	<2.4	<30	<1.8	<36
light	50-63	3.2- 5.3	27-44	2.4-3.7	30-47	1.8-2.5	36-51
moderate	64-76	5.4-7.5	45-62	3.8-5.1	48-64	2.6-3.3	52-67
hard	77-93	7.6-10.2	63-85	5.2-6.9	65-86	3.4-4.3	68-87
very hard	>94	>10.3	>86	>7	>87	>4.4	>88
maximal	100	12	100	8	100	5	100

This table shows the classification of relative intensity expressed in $\%HR_{max}$ and of absolute intensity with regard to different VO_{2max} values. The absolute intensity in this table is expressed by three different VO_{2max} basic levels or MET values. This means that a poor trained woman (VO_{2max}= 5 METs) exerts very light physical activity at 35 $\%VO_{2max}$, whereas a better trained woman (VO2max= 12 METs) needs 26 $\%VO_{2max}$ for the same effort.

Volume

The volume of activity is the product of absolute intensity, duration and frequency over a time period and is frequently used as a measure for the dose-response relationship between physical activity and health outcomes. It may be described in kilocalories, MET-min and MET-hours (Howley ET 2001).

1.1.1.2 Types of Physical Activity

Cardiorespiratory Activity

Cardiorespiratory Physical Activity consists of rhythmic and dynamic exercises that involve large muscle groups like jogging, dancing, swimming or hiking and improve the aerobic capacity. The assessment of VO_{2max} gives information about the fitness level that can be improved by regular physical activity. The required increase of VO_2 *max* values ranges from 5%- 30% and is proportional to the training induced stimulus (American College of Sports Medicine 2000, p.140)
Due to an increase of heart rate and energy expenditure, cardiorespiratory physical activity additionally changes the sensitivity of insulin and adrenalin and the concentration of the oxidative enzymes in the metabolism of fat and carbohydrates. Cholesterol fractions, triglyceride, blood pressure and abdominal fat may change by inducing an aerobic stimulus over a certain period of time (Froberg K 2005).
Compared to adults children often do aerobic exercise through running, hopping or swimming in short bursts with a permanently changing intensity (U.S. Department of Health and Human Services. 2008).

Resistance Activity

Daily activities demand muscular strength, power, endurance and mass for performing common tasks. The use of resistance training increases skeletal muscle strength, but has no or hardly influence on VO_2 *max* values. An overload beyond a minimal threshold makes muscles to do more work than usual and leads to an improvement of strength. The intensity of resistance exercise is influenced by the weight, the number of repetitions and reduced speed of movement (American College of Sports Medicine 2000, p.157).
In children and adolescents muscle strengthening exercise occur in daily activities and are mostly unstructured as part of playing (climbing trees, playing on playground equipment…). Structured programs contain resistance training or lifting weights (U.S. Department of Health and Human Services. 2008).

Flexibility

An adequate range of motion in all joints guarantees a good musculoskeletal functioning. Maintenance of flexibility can be achieved with preventive or rehabilitative exercise programs that are individual and specific to each joint. Stretching (static, dynamic or proprioceptive neuromuscular facilitation) can lead to a deformation of muscles at a lower tension, equated to good flexibility. Beside strict stretching exercises, yoga, pilates, tai-chi may also improve flexibility when appropriate (American College of Sports Medicine 2000, p.159).

Possible Activities for Children and Adolescents

The patterns of movement in children and adolescents differ from those in adults, insofar as diversification:

When children or adolescents rhythmically move their large muscles like they do in running, hopping, swimming, dancing or bicycling cardiorespiratory fitness is required. Physical activity is mostly unstructured as part of a game like climbing trees, playing on playground equipment and contains entrainments of the basic motor skills (U.S. Department of Health and Human Services. 2008, Glossary, U.S. Department of Health and Human Services 2008). The level of speediness, coordinative skills, rhythmicity, balance and sensitivity for the nature or the own person often gets trained during mainly short bursts with changing intensity. Adolescents tend to use structured activities in form of endurance, resistance or coordinative training found in activity games like ultimate Frisbee, slack lining, soccer, baseball, volleyball, dance, tennis, trend sports like snowboarding, skating, beach volleyball, dance and special exercise with weight- bearing elements (Titze et al. 2010, p.33).

1.1.2 Effects of cardiorespiratory activity in children and adolescents

Cardiorespiratory exercise causes short- and long-term physiological adaptive processes. The short-term response especially focuses on cardiac parameters that increase during exercise, but reach the basal level at rest again. Long term consequences of regular physical activity refer to a better health status of children and adolescents. A short overview of the beneficial impact of physical activity on health parameters in current literature should point out the importance of regular physical activity, involving the Physical Activity Recommendations that are realized in school intervention programs in order to sustain or improve pupils 'health.

1.1.2.1 Short-term physiological response to cardiorespiratory exercise

Physical activity, independent from mode, duration, intensity or volume requires energy above resting values, provided through oxygen. The cardiovascular and respiratory system have to cooperate in order to provide the working muscles with sufficient oxygen during cardiorespiratory exercise (Plowman, Smith 2008, p.252). As the doctoral thesis focuses on cardiac adaption after cardiorespiratory exercise, the background of cardiac response to physical activity is basically described.

Cardiac output

At the onset of moderate physical activity the bodily system is forced to respond with an increase of cardiac output (Q) to a plateau steady state within a few minutes (Figure 3). The cardiac output must be sufficient for the support of oxygen and metabolic demands (ATP production) (Plowman, Smith 2008, p.252).

Blood pressure

The heart regulates the blood outflow throughout the vascular circuit and responds to moderate aerobic exercise with an increase of the vascular area for blood flow. It means that the alteration of skeletal muscular contraction and relaxation during aerobic physical activity has an impact on the blood flow through the vessels to the heart. During moderate exercise the systolic pressure slightly increases within the first minutes to a plateau steady state (Figure 4), but the diastolic pressure remains stable (MacArdle, Katch & Katch 2006, p.335). It stays relatively constant due to peripheral vasodilation that facilitates blood flow to the active musculature. The mean arterial pressure increases slightly, linked to the development of the

systolic blood pressure (Plowman, Smith 2008, p.352). The higher the intensity and duration of the exercise, the faster is the increase of systolic values. In vigorous exercise the coronary blood flow is four to six times more active than at rest because of a high myocardial metabolism and increased aortic pressure (MacArdle, Katch & Katch 2006).

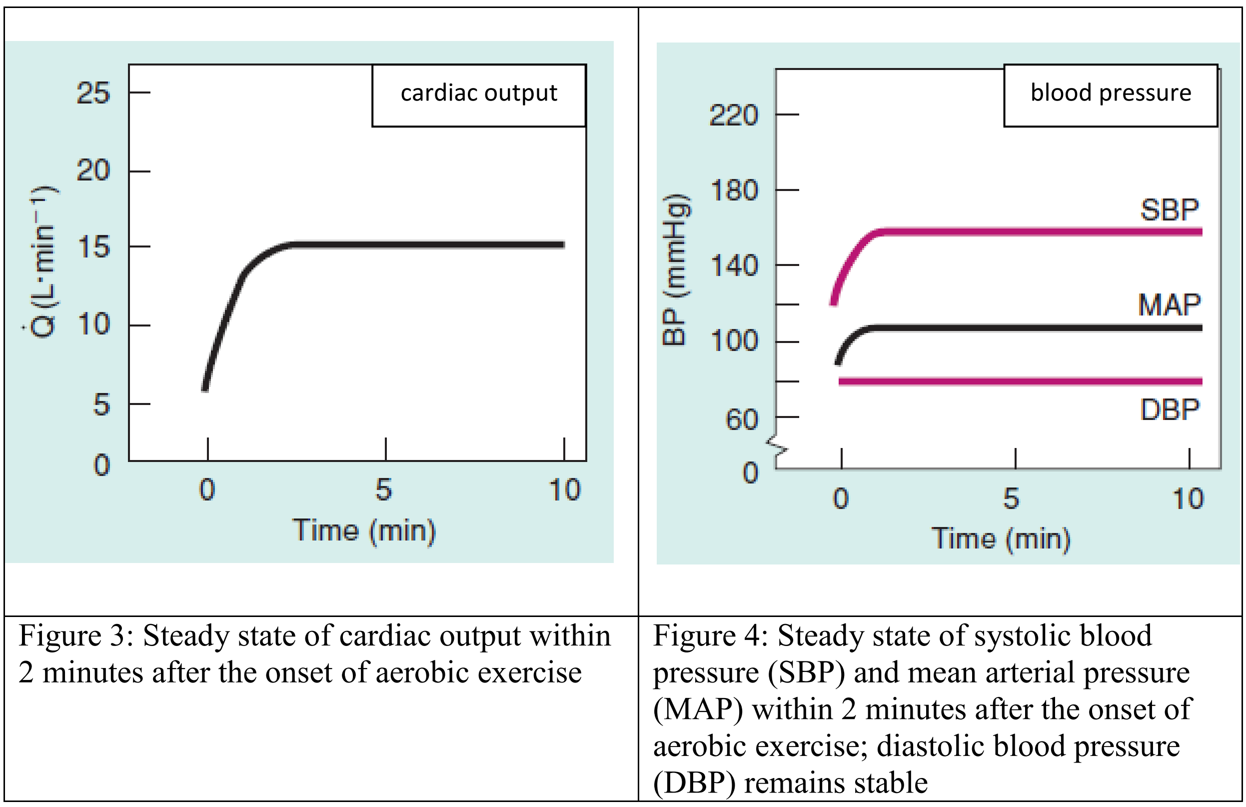


Figure 3: Steady state of cardiac output within 2 minutes after the onset of aerobic exercise	Figure 4: Steady state of systolic blood pressure (SBP) and mean arterial pressure (MAP) within 2 minutes after the onset of aerobic exercise; diastolic blood pressure (DBP) remains stable

Figures are adapted from (Plowman, Smith 2008, p.335)

The Figure on the left demonstrates the steady state of cardiac output within 2 minutes after aerobic exercise to ensure a sufficient oxygen transport for the support of metabolic demands. The Figure on the right shows the similar development of the systolic blood pressure and mean arterial pressure with the steady state. Diastolic blood pressure does not demonstrate any changes because of peripheral vasodilation (Plowman, Smith 2008, p.335).

Heart rate

Neural impulses and signals in the cardiovascular centre (the medulla) precede cardiovascular adaptive processes, meaning that the autonomic nervous system[1] with its sympathetic and parasympathetic modulation influences the heart rate. During moderate to vigorous exercise the sympathetic output is maximal and the vagal stimulation minimal, resulting in vasoconstriction. The cardiovascular system immediately responds to exercise with an increase of heart rate due to a reduction of vagal activity. Heart rate depends on the workload, increases proportional to the intensity and stabilizes. Hemodynamic cardiac contraction of healthy adolescents and adults returns to baseline within minutes after the trainings load; especially the reactivation of parasympathetic tone is an important deceleration mechanism (Fletcher et al. 2001). To maintain this cardiac adaption three mechanisms are necessary (Magder 2012):

- the central drive, a motor signal from cortex causes an increase of sympathetic output
- a regulative process of baroreceptors[2] responds to a changing arterial pressure
- the activation of peripheral afferent fibres is necessary for the change in heart rate

At the set point of the exercise the cardiovascular regulatory system increases heart rate and regulates blood flow in direct proportion to the intensity of the induced physical activity. Vessels in the active musculature are dilated by sympathetic cholinergic outflow and other factors. Especially neural and hormonal influences modify the heart´s inherent rhythm in an anticipation of exercise (MacArdle, Katch & Katch 2006). As exercise progresses the skeletal muscle blood flow, the oxygen extraction, the systolic blood pressure and the heart rate increase. Cardiac output can be enhanced to 6times more than at the baseline (Fletcher et al. 2001). These physiological adaptions depend on the intensity of the exercise session. Table 2 gives a short overview about the development of the cardiac parameters referring to different intensities.

Short-term, light to moderate	Long- term, moderate to heavy	Incremental to maximum

[1] Furthe

[2] “one c

Q	Increases rapidly; plateau at steady state within 2 minutes	Increases rapidly, plateau	Rectilinear increase with plateau at max
SBP	Increases rapidly; plateau at steady state within 2 minutes	Increases rapidly, plateau, negative drift	Rectilinear increase with plateau at max
DBP	Little or no change	Little or no change	Little or no change
MAP	Increases rapidly; plateau at steady state within 2 minutes	Increases initially	Small rectilinear increase
HR	Increases rapidly; plateau at steady state within 2 minutes	Increases rapidly, plateau, positive drift	Rectilinear increase with plateau at max

Table 2: Cardiac adaptions in dependence of the intensity adapted from (Plowman, Smith 2008, p.362)

Q…cardiac output, SBP…systolic blood pressure, DBP…diastolic blood pressure, MAP…mean arterial pressure, HR…heart rate,

This table summarizes the physiological response to exercise with different intensities: short-term can be understood as a period from 5 to 10 minutes and long-term greater than 30 minutes. Light intensity (30-49% of VO_{2max}) and moderate (50-74% of VO_{2max}) to heavy intensity (60-85% of VO_{2max}) cause similar increases in cardiac output, systolic blood pressure, mean arterial pressure and heart rate. The main difference is the positive drift in HR indicating an increased HR without a rise in speed or effort. The maximal intensity (up to 100% of VO_{2max}) provokes rectilinear increases in the mentioned parameters.

1.1.2.2 Health response to cardiorespiratory exercise from childhood to adulthood

Current literature (U.S. Department of Health and Human Services. 2008, Archer, Blair 2011, Oja et al. 2011, Murphy, McNeilly & Murtagh 2010) demonstrates that regular cardiorespiratory activity improves overall health and is associated with a decrease of mortality and morbidity in adults, but studies (Ganley et al. 2011, Ruiz et al. 2009, Ortega et al. 2008) with children and adolescents have at large been scarce, because the consideration of external processes like physical growth, biological maturation and behavioural development make the evaluation of individual and combined effects difficult.

Against this background the relationship between regular physical activity and adolescent health can be three fold. Figure 5 demonstrates the relationship of physical activity and adult health:

- "Physical activity during youth is related to health status during youth" (Twisk 2001). The adolescent health status may predict the adult health profile
- "Physical activity during youth is related to physical activity during adulthood" (Twisk 2001). As a relation between physical activity in adulthood and health do exist, it is important to find a way to maintain a sportive lifestyle.
- "Physical activity during youth is directly related to adult health status" (Twisk 2001). There is evidence that adverse lifestyle during childhood and adolescence lead to a risk of cardiovascular diseases whose clinical symptoms mostly become present much later

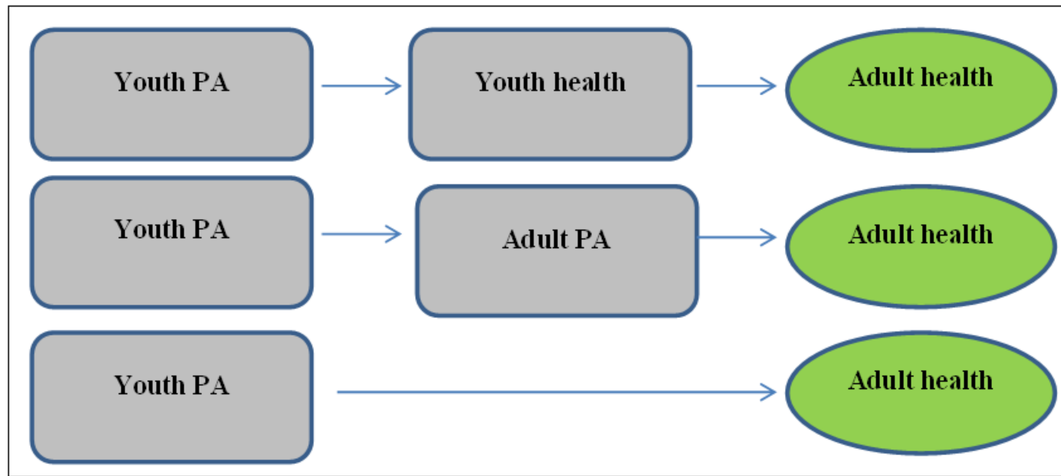


Figure 5: Possible relationships between physical activity (PA) during youth and health during adulthood, adapted from (Twisk 2001, p.619)

Cardiorespiratory Health

Cardiovascular disease (CVD) is the most common cause of death and may find its onset in childhood or adolescents, although the clinical symptoms occur much later in life (Froberg K 2005). In considering the effects of physical activity on cardiorespiratory health, two influences must be emphasized: the impact on the development of symptomatic diseases like heart attack or stroke and the impact on the risk factors, contributing the development of symptomatic disease. The modifiable risk factors are metabolic in nature and can be influenced by physical activity (U.S. Department of Health and Human Services. 2008, Part G 2-1).

These metabolic malfunctions result from an imbalance of insulin, adrenalin and metabolic hormones that are related to most of the CVD risk factors. The sportive aerobic stimulus causes the body to increase the sensitivity of insulin and adrenalin and the concentration of the oxidative enzymes in the metabolism of fat and carbohydrates. For that reason cardiovascular exercise demands changes in CVD risk factors like cholesterol, triglyceride, blood pressure and abdominal fat (Froberg K 2005).

(Ruiz et al. 2009) reviewed the relationship between cardiorespiratory fitness and regular aerobic activity and reported on seventeen high quality studies that found a significant correlation between CVD risk factors and the physical activity profile of children and adolescents. (Ruiz et al. 2009) confirmed the threefold relations suggested by (Twisk 2001) that an adverse lifestyle during youth favours CVD risk factors and predicts cardiovascular diseases in later life in the systematic review. There is strong evidence that high levels of cardiorespiratory fitness in childhood and adolescence are later associated with a healthier profile.

A notable example of a cross- sectional study linking physical activity with CVD risks during childhood is the European Youth Heart Study (Andersen et al. 2006). 1732 school aged children between 9 and 15 years from Denmark, Estonia and Portugal were involved. The study focused on the availability of measures for insulin resistance and other cardiovascular risks in children in relation to objectively measured physical activity. (Andersen et al. 2006) demonstrated that physical activity is important for the cardiovascular profile of children and adolescents and prevents clustering of cardiovascular risks factors.

All in all there is strong evidence that a high level of cardiorespiratory fitness is a health marker and has been related to a better risk factor profile in youth. Beside biological

determinations like sex, age, pubertal status and growth and genetic factors, aerobic activity contributes to a healthier cardiovascular profile in adult lifespan (U.S. Department of Health and Human Services. 2008, Ruiz et al. 2009, Martinez-Gomez et al. 2011, Martinez-Gomez et al. 2011, Carnethon et al. 2003).

Metabolic Health

Metabolic diseases are risk factors contributing to a higher prevalence of mortality and morbidity caused by cardiovascular diseases ranging from stroke to myocardial infarction (Archer, Blair 2011, Murphy, McNeilly & Murtagh 2010, O'Donovan et al. 2010). The most representative examples of metabolic diseases are the metabolic syndrome (47 million people in the US are affected) and diabetes (20.8 million people in the U.S (= 7% of the US population) are concerned). Type2 diabetes, once called adult-onset diabetes, is now alarmingly appearing in young people and its prevalence in children is constantly increasing (U.S. Department of Health and Human Services. 2008, Part G 3-1).

The positive impact of cardiorespiratory exercise on children with diabetes (improvement of insulin sensitivity, lipid profile, post-prandial glycaemic peak, reduction of daily insulin dosage and weight/fat accumulation) is well investigated (Giannini, Mohn & Chiarelli 2006). Therefore in current literature (Rachmiel, Buccino & Daneman 2007, McCall, Raj 2009, Mayer-Davis 2008) physical activity is suggested to be one component in order to cope with paediatric diabetes. However, concrete evidence about the effectiveness of physical activity in the prevention of diabetes is still lacking, probably linked to the low number of children having developed this disease, in comparison to adults.

Similarities to the diabetes research can be found in studies about the paediatric metabolic syndrome[3]. It is obvious that this disease can be reduced or stopped with regular physical activity (Strong et al. 2005, Steele et al. 2008), but the effectiveness of exercise on metabolic syndrome remains unclear.

[3] The metabolic syndrome is defined as metabolic disease with "high blood pressure, a large waistline, an adverse blood lipid profile and impaired glucose tolerance" (U.S. Department of Health and Human Services. 2008), but there is a lack of a universal definition; this fact limits the ability to compare studies.

Energy Balance

Overweight and obesity are associated with an increased risk of morbidity and mortality due to the high prevalence of developing hypertension, stroke, diabetes, respiratory problems and coronary heart diseases. Over the past years obesity has dramatically increased and has attracted interest within scientific research and media (U.S. Department of Health and Human Services. 2008).

"Obesity is defined as a condition where a pathological excess of body fat is present in an individual" (Wabitsch 2000). In the majority of reviews (Wabitsch 2000, Kaur, Hyder & Poston 2003, Chen, Binns & Zhang 2012), obesity is expressed according to age and sex classifications in percentage overweight or the body mass index (BMI)[4]. In childhood, adolescence and adulthood not obesity itself, but its consequences contribute to an adverse health status. Childhood obesity is associated with a wide range of negative medical events including metabolic disturbances, pulmonary, skeletal, orthopaedic, dermatological and immunological diseases, impaired mobility, and adverse social and psychological effects (Wabitsch 2000).

The systematic review of (Wilks et al. 2011), including 10 observational and 4 intervention studies on the relationship between physical activity and obesity in children and adolescents demonstrates that the increased energy intake is the main driver for developing adiposity during childhood or adolescence. For that reason intervention programs mostly focus on a combination of energy balance and physical activity. School- based programs (Verstraeten et al. 2012, Doak et al. 2006) consisting of a healthy dietary habits and physical activity promotion show high efficacy in adiposity prevention. The main finding of this systematic review, including 22 investigations on the effectiveness of school based obesity interventions is that physical activity and nutritional behaviour can be positively influenced through school-based prevention programs. This conclusion agrees with another systematic review evaluating 24 studies of obesity prevention through physical activity in children and adolescents: (Flodmark, Marcus & Britton 2006) concluded that school-based interventions offer the opportunity to prevent obesity in pupils.

Insufficient physical activity at any stage of growth and development during childhood and adolescence contributes to overweight and obesity (Hills, King & Armstrong 2007). For that reason physical activity, especially cardiorespiratory exercise has been an important part of

[4] The WHO defined the cut off point for overweight at a BMI of 25 and for adiposity at a BMI of 30

weight-loss programmes. (Janssen, Leblanc 2010) for example reported on significant changes in BMI, total fat and abdominal fat in response to aerobic exercise in their systematic review, but focused on further key indicators of physical activity induced health outcomes. Beside the high evidence that physical activity promotes health benefits this systematic review applies to the dose-response between physical activity and health: the more active, the greater the benefits.

Musculoskeletal Health

There is evidence for the beneficial role of physical activity on bone, joint and muscle health. In contrast to bone and joint health, muscle health is not linked with specific diseases, but makes a contribution to disease prevention through muscle quantity and quality (U.S. Department of Health and Human Services. 2008, G 5-1).

In children and adolescents, especially growth is an important issue linked to musculoskeletal health. The prepubertal skeleton is sensitive to mechanical stimulation and offers the ability to do daily activities without limitations (Vicente-Rodriguez 2006).

(Gunter, Almstedt & Janz 2012) reviewed the relationship between physical activity during childhood and skeletal health in lifespan and indicates that there is a positive influence of mechanical loading on the skeletal development. Physical activity builds bone mass and improves the structure of bone and joints contributing to bone health by overall strength. There is evidence that physical activity shows benefits in skeletal health during pre- and pubertal years. Enhanced bone mineral accrual and a good bone structure during childhood set the potential for skeletal benefits in later life. (Strong et al. 2005) specified the type of physical activity which is beneficial for bone health and indicated that muscle strengthening exercises or weight-bearing activities have a favourable influence on paediatric skeletal tissue like bone mineral content, bone mineral density and bone mineral apparent density.

An optimal bone structure with its interaction of joints and muscles has also a preventive diseases function during childhood. (Clark, Tobias & Ness 2006) for example systematically reviewed 10 case-control studies and came to the conclusion that there is an association between low bone mass and incidence of bone fracture in children and adolescents. Skeletal health appears to be clearly associated with physical activity. Especially a good development of bone mineral density and structure minimizes the risk of fractures during childhood and adolescence and offers sustained skeletal health in later lifespan.

Mental Health in general

Poor mental health reduces the quality of life. The scientific evidence supports the overall conclusion that regular aerobic physical activity is associated with improved emotional well-being and reduced symptoms of mental health disorders. Especially during childhood and adolescence symptoms of anxiety and depression, self-esteem and physical self- concept can be positively influenced by cardiorespiratory exercise (U.S. Department of Health and Human Services. 2008, G 8-1).

Indicators of mental health in youth were limited to self-concept, anxiety and depression; relatively little work has focused on other important aspects of mental health like stress or emotional distress (Strong et al. 2005, National Institute for Health and Clinical Excellence (NICE) 2007).

Depression

Depressive disorders have been identified throughout the life span, but the percentage (1%) of depression during childhood and adolescence is low. Very few studies focus on the relationship between depression and physical activity in children and adolescents. Hence, evidence from adult studies demonstrates that physical activity is inversely associated with symptoms of depression therefore there is supposition of that coherence in children and adolescents (National Institute for Health and Clinical Excellence (NICE) 2007). The systematic review of (Janssen, Leblanc 2010) for example- just 6 studies on physical activity and depression in children and adolescents met the inclusion criteria- came to the conclusion that the relation between physical activity and depression in youth is evident at a level of moderate intensity physical activity.

Anxiety

"Exercise may act as a distraction from anxiety- provoking situations and thoughts. Biochemical changes (e.g., in circulating neurotransmitters) induced by exercise may also lead to reductions in anxiety, as might the increase in core temperature and sense of well-being that occur during and after exercise" (Smith, Biddle 2008). (National Institute for Health and Clinical Excellence (NICE) 2007) reviewed cross-sectional studies and experimental studies and showed positive influences of physical activity on mental

parameters. The influence of physical activity in children and adolescents on depression is beneficial, but the evidence is weak.

Self-concept

Self-concept refers to different domains: academic to non-academic, social, emotional and physical. As the adolescence is a crucial period in which self- concepts are changed again and become clarified, it is important to find an intensifier for developing in a positive way. (Strong et al. 2005) reported on a positive association between physical activity and physical self- concept, but the association between physical activity and global, social and academic self- concept remains unclear. Self-esteem, part of the self- concept is seen as a key indicator of positive mental health and emotional well- being. Physical activity is associated with a production of good vibes and can be seen as transmitter of positive mood (Fox 1999).

Conclusion

The short-term response of cardiovascular exercise refers to an improvement of cardio autonomic parameters leading to a better cardiovascular profile in children and adolescents. Physical activity is associated with good cardiorespiratory fitness expressed as VO_2 *max* that can be increased 5% to 15% after aerobic training (Baquet, van Praagh & Berthoin 2003).

The long term response of cardiovascular exercise is strongly related to health benefits ranging from a decrease in cardiovascular and metabolic risk profiles, reduced symptoms of anxiety and depression to a favourable energy balance leading to lower body fatness. There is strong evidence that active young people compared to inactive have a better health profile during youth tracking to adulthood. According to the dose-response scientific research suggests high levels of activity. The minimal dose for being active is provided in diverse physical activity recommendations that are presented on the next pages.

1.1.3 Current physical activity recommendation for children and adolescents

As there is strong evidence for the positive influence of physical activity on the health status of children and adolescents, scientific research has focused on the dose response for improved health and fitness outcomes. Data were collected in order to create guidelines for the total population that exclusively support the health benefits and not the enhancing sport performance.

Historically, the earliest formal physical activity guidelines for youth were provided by the American College of Sports Medicine (ACSM) in 1988 who developed an opinion statement with the recommendation for 20- 30 minutes of vigorous exercise each day to achieve optimal functional capacity and health (American College of Sports Medicine 1988). In 1993 an International Consensus Conference on Physical Activity Guidelines (ICC) was organized in order to develop empirically based guidelines for children and adolescents. Recommendations for daily physical activity and at least 20 minutes of physical activity with moderate to vigorous intensity on three days per week were defined. In contrast with previous guidelines, the intensity and duration of activity was not included (Armstrong, Welsman 2006).

In 1995 the U.S. Centres for Disease Control and Prevention and the American College of Sports Medicine published recommendations with a concise public health message that focused on the amount and types of physical activity. These guidelines were adequate for adults, but not optimal for children and adolescents (Ward, Saunders & Pate 2007, p.17).

In 1998, the Health Education Authority symposium "Young and Active" (Biddle, Sallis & Cavill 1998, p. 3-16) suggested different recommendations of physical activity for children and adolescents. The first recommendation suggested a daily amount of one hour with at least moderate intensity; the second recommendation demanded activities that should help to enhance and maintain muscular strength, flexibility and bone health, at least twice a week (Twisk 2001).

Following those recommendations, there actually are several guidelines that are specialized on physical activity in children and adolescents. The most important and world-wide accepted guidelines will be introduced now.

The *Physical Activity Guidelines for Americans* (2008), developed from the Department of Health and Human Services (U.S. Department of Health and Human Services 2008) are the golden standard upon all recommendations. Current literature was reviewed and documented very strong evidence that physically active people have health benefits.

The key guidelines for children and adolescents aged between 6 to 17 years, suggest that they should participate in 60 minutes or more of daily physical activity. The activity should include aerobic, muscle strengthening and bone strengthening elements: most of the at least 60 minutes should include aerobic activity with moderate to vigorous-intensity and vigorous intensity at least 3 days a week and muscle- and bone strengthening activities on at least 3 days of the week.

The recommendations of the *World Health Organisation (WHO)* (World Health Organization 2010) are relevant to children aged between 5- 17 years and are based on the U.S guidelines. Children and adolescents, irrespective of gender, race or ethnicity should participate in different kinds of physical activities that support the natural development. Physical activity includes playing, games, sports, transportation, recreation, physical education or planned exercise. Collectively, research suggests an amount of 60 minutes per day of moderate- to vigorous physical activity irrespective of performing shorter bouts (2 bouts of 30 minutes). Certain specific types of physical activity must be included in order to gain health benefits. On three days per week resistance exercise to enhance muscular strength and moderate to vigorous aerobic exercise to improve cardiorespiratory fitness should be carried out.

The *Austrian Guidelines* (Titze et al. 2010) for physical activity, published 2010 were also based on the U.S recommendations for youth (2008).

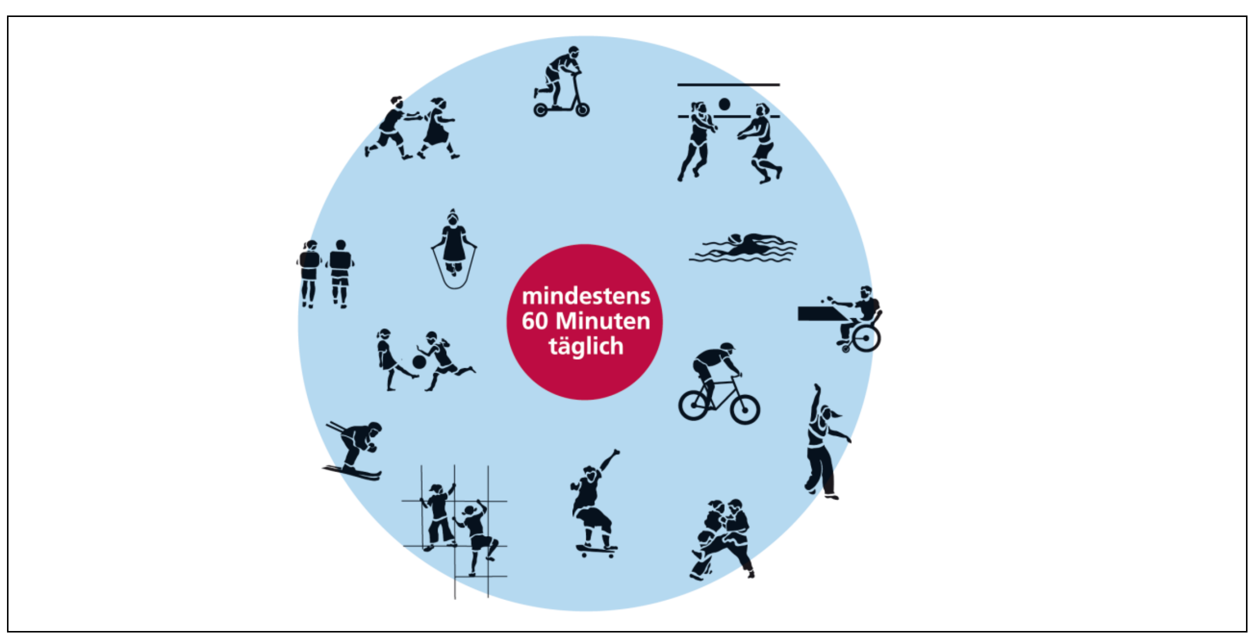


Figure 6: Austrian Physical Activity Guidelines for Children and Adolescents, adapted from (Titze et al. 2010)

Figure 6 demonstrates the Austrian Guidelines for children and adolescents. For achieving health benefits youth should accumulate 60 minutes of at least moderate intensity daily physical activity. Muscle and bone strengthening activities and exercise for improving coordination and flexibility should be done three times a week. In addition, short bouts of physical activity are recommended after a sedentary time of at least one hour.

1.2 Chronobiology and its circadian rhythms

As sleep is a part of circadian rhythms this chapter gives a short introduction about chronobiology with its circadian rhythmicity. Basic knowledge around sleep with its functions leads to the physiological background of autonomic modulation during sleep with heart rate variability (HRV) as an indicator of sympathetic and parasympathetic outflow. During adolescence the sleep structure gets changed: a short overview about sleep during adolescence should offer the main changes and difficulties of adolescent sleep. The last subchapter accomplishes the main research topics, physical activity and sleep: the impact of physical activity on sleep is described and leads to the research questions.

1.2.1 Circadian rhythms - an introduction

Biological rhythms appear in the complete organsism as well as within each living cell. Some of these rhythms may reflect adaptions to cosmic cycles and help humans in the anticipation to external influences and enviromental changes (Moser, Fruhwirth & Kenner 2008, Grote et al. 2013). Chronobiology has identified lots of different rhythms in the bodily and cellular systems. Some of these rhythms are affected by environmental influences, others run of their own (Moser et al. 2006, Hildebrandt, Moser & Lehofer 1998). Biological rhythms can be found in many time domains, ranging from milliseconds up to years with fluctuations over a 24-hours period. Such fluctuations are called circadian rhythms that have fundamental effects on physiological functioning (Atkinson, Jones & Ainslie 2010). Current literature (Moser et al. 2006, Lehofer et al. 1997, Moser et al. 1998) shows that chronobiological rhythms are associated with well being and health.

Circadin rhythms, i.e. biological regulators in organisms ranging from unicellular organisms to humans controle the daily hormonal and behavioural system. They are able to influence sleep/wake cycle, cortisol and melatonin flow, core body temperature, subjective alertness and performance levels (Lack, Wright 2007). (Weinert, Waterhouse 2007) defined circadian rhythms as “inherent property of living systems” that “ constitute an essential part of their internal and external temporal order”. To guarantee efficient funcioning of the biological network these rhythms interact with the bodily system and externe influences (Weinert, Waterhouse 2007). Brief, the circadian system with its circadian pacemarker provides a

temporal order in physiological and behavioral events and is able to regulate hormone production, brain activity and cellular, biological and biochemical processes (Scott 2011).

The circadian pacemarker, located in the suprachiasmatic nucleus (SCN), the anterior hypothalamus above the optic chiasma regulates endogenous rhythms. This regulation lasts approximately 24,2 h (Czeisler et al. 1999). Entrainment of the circadian pacemarker (setting the clock time) is influenced by photoperiodic information of the light/dark cycle that is recognized by the suprachiasmatic nucleus via the optic nerve. This light/dark event is converted into action potentials by photoreceptors. The hormonal response with its melatonin production conveys information of the light/dark cycle to every tissue of the body. This leads to an indication of time or phase management (Lack, Wright 2007). The internalized image of external rhythms helps to anticipate external changing influences(Moser, Fruhwirth & Kenner 2008, Moser et al. 2006). To establish and stabilize the biologic rhythms "Zeitgebers", defined by Aschoff in the 60s, do exist. Examples for such "Zeitgebers" are the morning light adverting to the beginning of the day, temperature or meals (Aschoff 1965).

The ergotropic functions (work, food…) are needed during the day; the trophotropic functions (immune system, regeneration…) occur during night. Those rhythms within their internal and external interaction stabilize the functioning of biological processes (Moser, Fruhwirth & Kenner 2008).

Sleep-wake cycle

Although the human sleep-wake cycles and circadian rhythmicity are closley connected, there is a seperation in between (Dijk, Lockley 2002). The coordiantion of humoral, physiological and behavioural mechanisms for sleep/wake promotion underlies the circadian timing system with a 24 hours schedule by temporal cues[5] in the environment. Sleep is operated through an internal timing mechanism, the circadian clock ((Pinel J. 2006, p. 353). Clock genes generate endogenous clock pulses in different cells with a synchronisation elicited by the hypothalamic master clock, the suprachiasmatic nuclei (SCN). Hence, the interaction of sleep and circadian rhytmns work in a bidirectional way (Lange, Dimitrov & Born 2010).

[5] One important cue is the dark/light cycle

The sleep- wake cycle is affected by two independet processes: the homeostatic sleep drive and the circadian influences. It means, that the homeostatic process includes an increasing sleep drive due to an energy uptake rate during wakefulness. The circadian process involves self- sustaining 24h rhythms that have an impact on sleep (Lack, Wright 2007). The circadian rhythm with its biological clock assumes responsibility for the timing and the duration of the daily sleep- wake cycle. The homeostatic process regulates the length and depth of sleep with regard to the timing, duration and quality of the previous sleep period (McLaughlin Crabtree, Williams 2009). (Borbely, Achermann 1999) were the first to describe a model to explain the interaction between the homeostatic and circadian component. When the homeostatic process reaches an upper threshold then sleep occurs and vice versa. According to this theory the sleep wake cycle depends on the relation between those two thresholds (Crowley, Acebo & Carskadon 2007). Figure 7 demonstrates the two process model of sleep regulation.

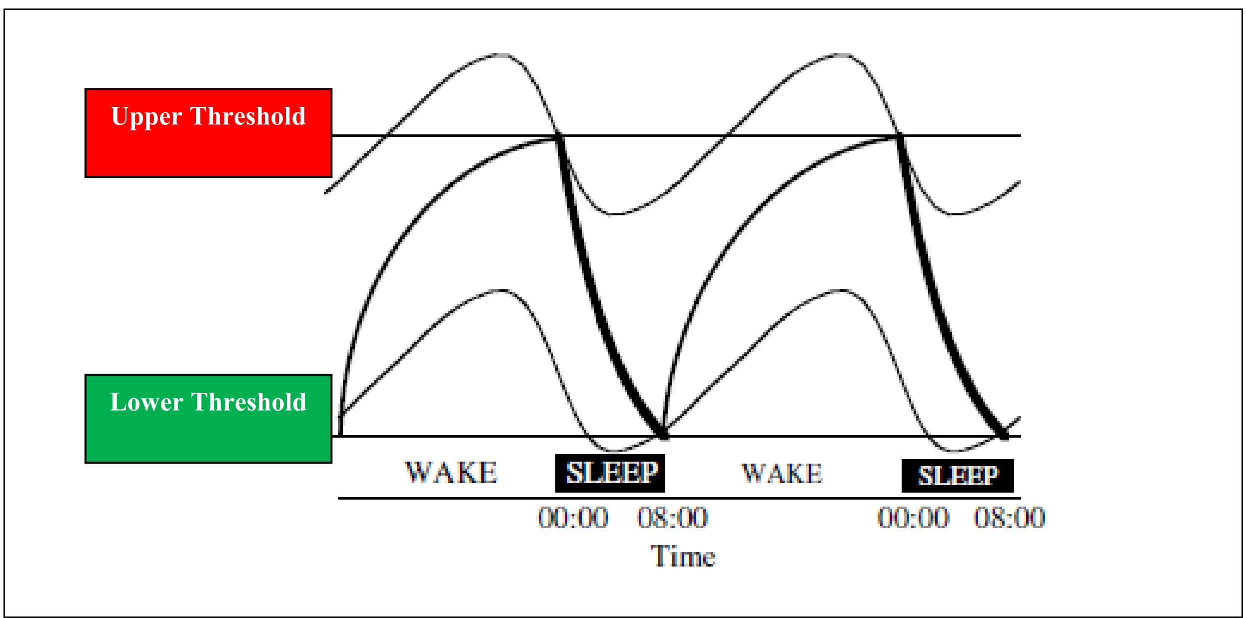


Figure 7: The two process model of sleep: bold lines (=the homeostatic process) accumulate during wakefulness and decline during sleep. The circadian process regulates the timing of sleep; this means that sleep pressure in the upper threshold initiates sleep and sleep pressure in the lower treshold induces wakefulness, adapted from (Crowley, Acebo & Carskadon 2007, p.606)

The homeostatic factor refers to an increased level for sleepiness with longer periods of prior wakefulness; the circadian factor refers to variations in physiological alertness and sleepiness occuring in cycles (Chokroverty 2010). This interaction of the homeostatic and the circadian

processes provides a basis for the timing and duration of sleep with an adopted intensity(Gordijn et al. 1999). The propensity to fall asleep happens due to the rapid circadian increase of sleep need, occurring about 2 hours after the onset of nocturnal melatonin secretion and the decrease of core temperature (Lack, Wright 2007). As mentioned above the SCN affects sleep timing with a wake or arousal signal. This nuclei increases during day and night, reaching a minimum at 6 o´clock. The onset of falling asleep starts after maximal circadian wake propensity and ends after maximal circadian sleep propensity with regard to proportion of the light, body temperature and melatonin rhythms(Dijk, Lockley 2002). The interaction of circadian and homeostatic processes generates the sleep timing and structure sleeping phases.

1.2.2 Sleep

Starting with definitions of sleep from the behavioural and physiological point of view, the sleep stages are explained. Physiological processes during sleep occur that are based on the modulation of the autonomic nervous system (ANS) with heart rate variability (HRV) as an indicator for autonomic functioning. Beside the physiological background the functions of sleep are mentioned. Information about the changed sleep structure with its problems during adolescence is offered leading to the main focus, the impact of physical activity on sleep.

1.2.2.1 Definition of sleep and its stages

From the behavioural point of view (Carskadon, M.A., & Dement, W.C 2011) defined sleep as follows: "According to a simple behavioral definition, sleep is a reversible behavioral state of perceptual disengagement from and unresponsiveness to the environment. It is also true that sleep is a complex amalgam of physiologic and behavioral processes. Sleep is typically (but not necessarily) accompanied by postural recumbence, behavioral quiescence, closed eyes, and all the other indicators one commonly associates with sleeping. In the unusual circumstance, other behaviors can occur during sleep. These behaviors can include sleepwalking, sleeptalking, teeth grinding, and other physical activities".

(Chokroverty 2010) expanded the behavioural definition: "The behavioural criteria consist of a lack of mobility or slight mobility, slow eye movements, characteristic specifies- specific sleeping posture, reduced response to external stimulation, increased reaction time, elevated arousal threshold, an impaired cognitive function and a reversible unconscious state," with a physiological insight related to the different sleep stages: "The physiological criteria are based on the findings of electroencephalogram (EEG), electro-oculography (EOG) and electromyography (EMG)".

The electroencephalogram (EEG), electrooculogram (EOG) and neck electromyogram (EMG) are the three standard psychophysiological measurements for determining and defining sleep stages. Referring to the EEG there are two separate states based on physiologic parameters: rapid eye movement (REM) and non-rapid eye movement (NREM) (Pinel J. 2006, p.349 f.):

NREM

The EEG image during NREM sleep is characterized by sleep spindles, K- complexes and high voltage slow waves. NREM is associated with poor mental activity, but a moveable body, decreased responsiveness to external events, accompanied by slow eye movements (Chokroverty 2010). It can be classified into four stages (Carskadon, M.A., & Dement, W.C 2011, World Health Organization 2004) :

Stage 1 NREM

After closing the eyes and beginning to fall asleep alpha waves (8 to 12 Hz) are active, inducing the transition to stage 1 NREM; it is a low- voltage, high-frequency signal that is similar to wakefulness, but slower than in being awake (Pinel J. 2006, p.349 f.). Characteristics are a relatively high muscle tonus and the presence of slow rolling eye movements, lasting only a few minutes at the onset of sleep (Carskadon, M.A., & Dement, W.C 2011).

Stage2 NREM

Due to an increase in EEG voltage and a decrease in EEG frequency stage 2 can be initiated with two characteristic wave forms: K complexes and sleep spindles. Each sleep spindle exhibits 12 to 14 Hz. Stage 2 is associated with a decrease in muscle tone leading to a basic recovery. It occupies 50% of the sleep period and lasts 10 to 25 minutes (Akerstedt, Nilsson 2003).

Stage 3 and 4 NREM

Stage 3 is defined by the occasional presence of delta waves and stage 4 is determined by a predominance of delta waves. Delta waves are the largest and slowest waves with 1 to 2 Hz (Pinel J. 2006, p.349 f.). Stage 3 and 4 are often classified together into slow wave sleep (SWS). This period demands a decrease of the muscle tonus and represents the daily process of restitution. A large increase of growth hormones and a suppression of cortisol secretion are observed during SWS. Stage 3 and 4 are characterized by slow breathing, low heart rate and low cerebral blood flow (Akerstedt, Nilsson 2003).

REM

In contrast REM sleep is not subdivided even though tonic and phasic types of REM sleep do exist. The REM stage is defined by EEG activation, fast rhythms and theta waves, rapid eye

movements and loss of core muscle tone. The high mental activity during REM sleep is associated with dreaming (Carskadon, M.A., & Dement, W.C 2011). The regulation of the main physiological functions is degraded, but the metabolic rate (phasic swings in blood pressure and heart rate, irregular respiration and phasic tongue movement) is increased.

During REM the sleeper is dreaming, but the efferent signals to the skeletal muscles are blocked. Briefly, REM sleep is characterized by a high active brain in a paralyzed body (Akerstedt, Nilsson 2003).

NREM and REM sleep alternate in cycles through the night. The length of both stages differs across the night: REM episodes become longer and slow wave sleep occupies less time in upper cycles. The first NREM- REM cycle lasts about 70- 100 minutes and later cycles have an average length of 90- 120 minutes during the night. NREM sleep counts about 75% to 80%, REM sleep about 20% to 25% of total sleep time (Carskadon, M.A., & Dement, W.C 2011). Figure 8 shows the cyclic alteration of NREM and REM sleep of a 14- years old girl.

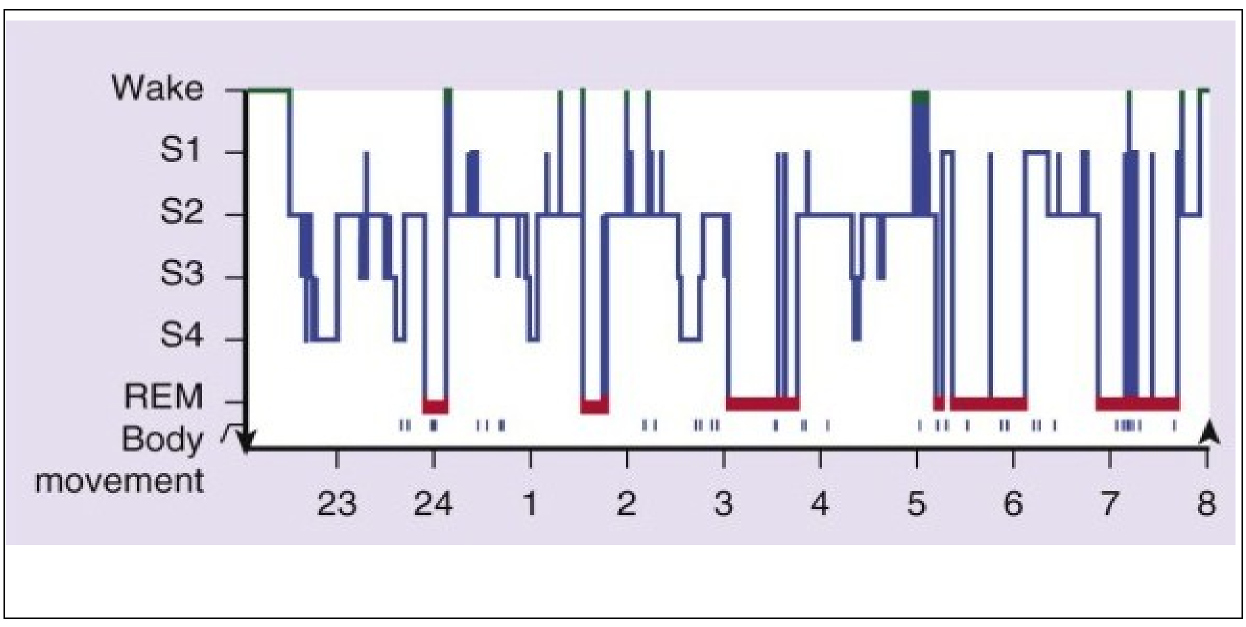


Figure 8: This histogram shows the sleep cycles of a 14- years old girl, adapted from (Carskadon, M.A., & Dement, W.C 2011, p.11)

Conclusio

Sleep is a complex state that is characterzied by an unresponsiveness to external stimuli from the behavioural point of view and by physiological adaptive processes dominated by different sleep stages contributing to a typical sleep cycle from the physiological point of view: physiological changes during sleep occur.

1.2.2.2 Physiological changes in sleep

As mentioned above sleep is a high active state where NREM and REM- cycles with neuronale activations and modulations are dominant. To sustain the motoric activity and attendance to externe and interne stimuli physiological processes are very active:

Core temperature

The core temperature as a substitute of the circadian system is fluctuating over a 24- hours period up to 1°C. The daily maximum is reached before falling asleep and the minimum is achieved during the morning hours. On the one hand the minimum of temperature arouses sleepiness and on the other hand about 30- 90 minutes of the minimum the REM sleep start (Maurer JT, Schredl M, Weeß HG 2009). During REM sleep core temperature can not be controled. Temperatur underlies circadian changes of the rate of heat dissipation through extremities. This mechanisms are also involved in the thermoregulation during physical activity (Zisapel 2007).

Hormones

The bidircetional interaction between sleep and the circadian system has influence on the hormonal level. During the night growth hormones and prolactin reach the highest discharge. Together with increased slow wave sleep (SWS) and low levels of REM sleep during the first part of the night there is a great release of growth hormones (Akerstedt, Nilsson 2003). In contrast, the activity of the two stress axes with their effector hormones cortisol and catecholamines decreases during sleep (Lange, Dimitrov & Born 2010). Those glucocorticoids are essential for the waking, alterness and stress response. The quality of sleep seems to depend on an interaction of growth releasing and corticotropin releasing hormones and on alterations in their release (Akerstedt, Nilsson 2003).

The regulation ob the body weight is also influenced during sleep. The concentration of the repressing appetit hormone leptin increases and ghrelin decreases (Maurer JT, Schredl M, Weeß HG 2009).
Melatonin is very important for sleep. This hormone, produced by the pineal gland at night serves as a time cue to the biological clock. In addition it promotes sleep anticipation in brain activity patterns: this background may explain the increase in sleep propensity at night(Zisapel 2007).

The cardiovascular system

The position of normal sleep is horizontal. The increasing venous back current of the periphere leads to a quicker filling of the right atrium and an increase of the right ventricular stroke volume. As a consequence the atrial peptid and renin are diminished. During sleep this diuretic effect reverses in order to have a volume balance. During the sleep onset the sympathetic tone declines and the parasympathetic tone increases. This physiological fact leads to a reduction in cardiac output. One reason for this development might be the decrease of heart rate frequency and left ventricular stroke volume (Maurer JT, Schredl M, Weeß HG 2009).
Blood pressure is characterized by a nocturnal fall and a diurnal rise. Systolic values decrease to 10-20 mmHg at night in normotensive and hyptertensiv humans. The rhythm of blood pressure is meadiated by the circadian rhythm of sympathetic tone. The activity of the sympathetic nerve, the blood pressure and the heart rate decrease during normal sleep (Zisapel 2007). The modulation of cardiac parameters is under control of the autonomic nervous system.

1.2.2.3 The relationsship between cardiac autonomic modulation and HRV

The regulation of physiological adaption happens due to the autonomic nervous system (ANS) that transmits impulses from the central nervous system (CNS) by mostly efferent fibres. It conveys sensory impulses that often do not reach the humans´ consciousness and effects heart rate, heart contraction, blood flow, smooth muscles in different organs and glandular secretions. The ANS consists of two different divisions, the parasympathetic and

sympathetic system, based on different anatomical and functional separated centres (Freeman et al. 2006). Table 3 shows the cardiovascular functions of the ANS.

The parasympathetic modulation of the heart

The parasympathetic tone dominates in quiet and relaxed situations and is modulated through the vagus nerve (Xth cranial nerve) that carries fibers to all organs. Due to the interaction of the chemical transmitter acetylcholine with muscarinic receptors all bodily functions are slowed down (Mohrman, Heller 2006, p.171). This vagal hormone retards the sinus discharge rate to decelerate the heart without having impact on the myocardial contractility (MacArdle, Katch & Katch 2006). The conservation and restoration of energy cause a decrease of heart rate and blood pressure. The slowdown of the heart is termed bradycardia as a response to vagal modulation. Vagal outflow depends on age and the fitness status of humans (Freeman et al. 2006).

Sympathetic modulation of the heart

The sympathetic tone dominates in stress full situations as a "flight or fight" response and is modulated through sympathetic preganglionic fibers that are located in the lateral horns of spinal segments T1 through T2. By stimulation of nicotinic, adrenalin and noradrenaline are transmitted and force the body to increase the cardiovascular system. A rise of heart rate, blood pressure and cardiac output enables the body to respond to stressful situations or challenges. The actions of catecholamines (epinephrine and norepinephrine), mediated by α and β receptors augment myocardial contractility and accelerate S-A node depolarisation (MacArdle, Katch & Katch 2006, p.373); it leads to an increase of the heart rate, defined as tachycardia and cardiac output with a diversion of blood flow from skin to the skeletal musculature (Freeman et al. 2006).

Table 3: The autonomic nervous system (ANS) with its cardiovascular functions, adapted from (MacArdle, Katch & Katch 2006, p.373)

Parasympathetic influence	Sympathetic influence
Decreases heart rate	Increase heart rate
Decrease of myocardial contraction force	Increase of myocardial contraction force
Distension of coronary blood vessels	Constriction of coronary blood vessels
Constriction of muscle and skin blood vessels	Distension of muscle and skin blood vessels
Distension of blood vessels in abdomen, muscles, skin and kidney	Constriction of blood vessels in abdomen, muscles, skin and kidney

HRV as an indicator of cardiac modulation

As mentioned above heart rate (HR) is modulated by the sympathetic and parasympathetic nervous system. The measurement of changes in heart rate over time of the period between consecutive heartbeats, called heart rate variability (HRV) gives information about autonomic functioning (Stein, Pu 2012a). HRV is dependent on the extrinsic regulation of heart rate and reflects the responsiveness of the heart to extern stimuli and changing circumstances (Rajendra Acharya et al. 2006a).

Historically, the roots of the first relevant studies of HRV are found in 1733, when Hales examined the breathing patterns and the pulse of horses (Hales 1733, Billman 2011). Hales (1733) reported on a synchrony of a beat-to-beat heart rate variability with respiration. Although temporal fluctuations in cardiovascular recordings were observed, physicians have overlooked for a long time the possible significance of the beat-to-beat fluctuation. This variability has generally been ignored (Mäkikallio 1998).
The clinical interest increased when Wolf (Wolf 1967) in (Task Force 1996) and Hon & Lee (Hon, Lee 1963) in (Task Force 1996)showed the relation between heart rate variability and autonomic nervous system. Since the power spectral analysis of heart rate fluctuations to beat- to- beat cardiovascular control has been introduced (Akselrod et al. 1981) in (Task Force 1996)components of heart rate behaviours have received attention.
These frequency domain analyses contributed to an autonomic feedback system of RR interval fluctuations and got clinical importance in the late 80s with regard to the strong

evidence for HRV analysis as predictor of mortality after an acute myocardial infarction (Task Force 1996).

In 1996, the European Society for Cardiology and the North American Society of Pacing and Electrophysiology supported a Task Force (Task Force 1996) that has become popular among published HRV papers. Reference normal values for HRV in healthy adults were published as an appendix to the paper. The prevalence of HRV as a measurement of autonomic function studies has begun (Nunan, Sandercock & Brodie 2010).

To investigate cardiac autonomic modulation, HRV analysis has become an important non-invasive measurement with a good reproducibility and is actually the most reliable and widely used tool for assessing sympathetic and vagal functioning of the ANS (Rajendra Acharya et al. 2006a).

It is possible to analyse HRV in time and frequency domains:

Time domain measures determine the heart rate at any point in time or the "intervals between successive normal complexes". Time domain variables include the mean normal-to-normal (NN) intervals, the "difference between the longest and shortest NN interval", "the difference between night and day HR" and the mean HR (Task Force 1996).

Frequency domain measures give information about the power spectral density. Nonparametric (Fast Fourier Transformation) or parametric (autoregressive modelling) methods can be used for the distribution of power as a function of frequency (Task Force 1996).

The overall variability is represented as total power with different spectral components: three main spectral components can be identified: very low frequency (0.01-0.04 Hz), low frequency (LF: 0.04-0.15 Hz) and high frequency (HF: 0.15-0.4 Hz). The difference in frequency domains makes a separation of sympathetic and parasympathetic contributions possible (Rajendra Acharya et al. 2006b). The high frequency band reflects the vagal activity, while the low frequency band is considered as a marker of both, parasympathetic and sympathetic activity. In spite of this fact the LF band always increases with sympathetic stimulation. This leads to the assumption that a rise in the LF band is a sign for sympathetic drive to the heart. Nevertheless, the LF power is difficult to analyse due to its vagal and sympathetic modulation within baroreceptor activity (Cabiddu et al. 2012). The significance

of high frequency bands is better understood than the low frequency components (Rajendra Acharya et al. 2006a).

As sleep is a highly active state that is influenced by autonomic regulation of cardiovascular activity, HRV is assimilated (Cabiddu et al. 2012).

In healthy people changes of the autonomic cardiovascular regulation with its parasympathetic and vagal interaction induces and indicates different sleep stages. Physiological and behavioural changes are commonly noted in the somatic and autonomic nervous system (Chokroverty 2010).
Heart rate and HRV decrease during NREM sleep stages and show an increase in the REM period (Stein, Pu 2012a). NREM sleep is characterized by a dominance of vagal outflow and a decrease of sympathetic tone. This condition leads to a relative stability with low heart rate and blood pressure. Due to the vagal predominance high frequencyy components dominate NREM sleep. This stability is broken during REM sleep where fluctuations between parasympathetic and sympathetic tone occur. This sleep stage produces changes in heart rate and blood pressure that is shown in a significant increase of low frequency components (Lanfranchi et al. 2007).

1.2.2.4 Functions of sleep

Sleep demand depends on the amount of sleep deprivation and the interaction of circadian and homeostatic processes. Those components regulate the sleep propensity at night and the bout of wakefulness during the day (Zisapel 2007). The question of “why do we sleep” has not exactly been answered in current literature, but nevertheless there are three main functions of sleep (Mignot 2008).

Function of decreased energy demands
Evolutionally, the energy expenditure was reduced when food was scarce. This reduction of energy demands can also be observed during sleep with a decrease up to 10%. Especially the brain energy expenditure is affected as it is a big part of total body energy (~30% in humans) (Mignot 2008). The proess of saving energy is molecularly sustained by releasing adenosin by glial cells(Benington, Heller 1995). As there is a relationsship between energy supply and

sleep, long term sleep deprivation leads to metabolic dysregualtions (Maurer JT, Schredl M, Weeß HG 2009, Wilhelm, Prehn-Kristensen & Born 2012).

Restorative function

Fatigue comes up after a period of wakefulness and activity and is a natural feeling inside. The background of restorative sleep is the ability to wake up with renewed power being fit for challenges again. If this restoration can not be ensured, the physiological and psyhological functioning of the body is limited, leading to health problems after a long time of dissturbed sleep. From the quantitative and qualitative point of view sleep is an important state that offers restorative processes (Zisapel 2007): the increase of growth hormones after the sleep onset, the replenishment of the cerebral glycogen stores and the intensified delta power sustain the restorative function (Maurer JT, Schredl M, Weeß HG 2009).(Moser, Fruhwirth & Kenner 2008)

Memory consolidation

Different sleep stages influence the process of memory consolidation and higher cortical functions like attention or cognition (Zisapel 2007). There is evidence (Mignot 2008, Wilhelm, Prehn-Kristensen & Born 2012) that learning and memory capacity can be improved by sufficient sleep without repetition of the task, because the information processing during sleep is effective.

Especially for children and adolescents the processes of memory consolidation is important for gaining declarative knowledge from a quantitative and qualitative point of view. Quantitative means an increased number of recalled words and qualitative refers to enhanced implicit to explicit conversion of knowledge (Wilhelm, Prehn-Kristensen & Born 2012).

1.2.3 Sleep during adolescence

Adolescence, the period between the onset of puberty and the acquisition of sexual maturity and adulthood, is an important period that is characterized by changes in cognitive, social, behavioral and emotional development. Adolescents have to cope with new roles and demands in the familial and social network (LeBourgeois et al. 2005) that arises wishes for independence, peer activities outside the familal strutures and other behavioral changes (Jenni, Achermann & Carskadon 2005). Although changes of the sleep architecture gradually occur during the whole life in relation to growth, stability and regression within somatic, neural, social, beavioral and cognitive functioning, during adolescence the greates changes in sleep patterns appear. Apart from modifications in physiological and homeostatic regulation, sleep habits differ to those in childhood; the tendency to shift to later bedtime or more eveningness leads to a different chronobiological profile (Colrain I., Fau-Baker & Baker F. 2011).

Sufficient sleep is an important component for growth and development in adolescence. For optimal daytime functioning, an adolescents needs 8-9 hours of adaquate sleep (Foti et al. 2011). Processes like growing expression of autonomy, the increase in academic obligations and social opportunities with late evening activities contribute to a change of behavioral sleep regulation during adolescence (Carskadon, Acebo & Oskar 2004). The timing of sleep undergoes a phase delayed circadian rhythmn that is influenced by changes in the period of the biological clock, a higher sensitivity to light or a different homeostatic sleep regulatory. Changes in sleep quality and quantity interact with the changing social and biological setting of adolescence {{32 Colrain IM ;}}. These all in all modulations relate to the timing of sleep and sleepiness and a different composition of sleep and wake EEG patterns: reduction in slow frequency activity and slow wave sleep. The maturation of the sleep structure undergoes gradual reductions in the proportion of deep non- REM sleep and increases in light non- REM sleep stages {{36 Hoban TF ;}}. Adaptions in brain and sleep behaviour to adolescental circumstances lead to insomnia-like problems {{32 Colrain IM ;}}. A decrease in total sleep duration that is dependent from school demands can be observed. During the academic year the inbalance of later bedtimes and earlier rise times is adjusted to the school schedules (McLaughlin Crabtree, Williams 2009).

Sleep-wake patterns undergo significant reorganisations during the onset of adolescence. (Sadeh et al. 2009) has summarized the main changes during this period as follows:

- a delayed sleep phase in relation to the onset of puberty;
- shorter sleep leads to increased levels of daytime fatigue;
- decrease in delta NREM sleep leads to increased sleepiness;
- greater tolerance for sleep deprivation in dependance on maturation;
- development of irregular sleep patterns with irregular sleep structure (little sleep duration during the weeks, compensation for the sleep loss during weekends);

Growing evidence supports the theory that changes in sleep reflect a developing circadian and homeostatic system. As the circadian system seems to be not static after prenatal development, the internal clock interprets environmental time in a different way compared to adults. It means that the number of components "including free- running period, continuous and discrete entrainment mechanisms, and recovery from photic phase shift" (Hagenauer M. et al. 2009) change during puberty. Current literature ((Crowley, Acebo & Carskadon 2007, Jenni, Achermann & Carskadon 2005, Hagenauer M. et al. 2009, Carskadon, Acebo & Jenni 2004)) supports the theory that biologic processes and not the psychosocial environment drive the sleep phase delay. There must be a change of sleep-wake cycles related to biological functioning and its circadian regulation during adolescence. Referring to the two-fold process model mentioned above (homeostatic and ciradian processes dominate the sleep-wake cycle) puberty correlates with the circadian phase marker. The sleep phase delay may be dependet from specific alterations of the circadian timing system (Jenni, Achermann & Carskadon 2005); more mature children have a later melatonin-secretion offset. The shift of the circadian phase may be related to a divergent ciradian clock with a changing sensitivity to evening or morning light (Carskadon, Acebo & Jenni 2004). Beside the circadian clock as coordinator of the sleep-wake cycle, the homeostatic processes also play an important role in pubertal sleep regulation, but are not entirely understood. Homeostatic and circadian phases are independent from eacht other; a simple example for this therory is that sleep pressure increases the longer an adolescent is awake and dissipates during sleep (Crowley, Acebo & Carskadon 2007). (Jenni, Achermann & Carskadon 2005) conclued in the study about the homeostatic processes during adolescence that sleep homeostasis shows specific maturational changes. The increase of sleep pressure during waking is slower in adolescents than in children; the nocturnal dissipation remains similar.

Adolescents lose the ability to maintain sufficient sleep. There is a decrease in total sleep time of about 2 to 3 hours, resulting in cumulative sleep dept. Differences between weekend and school day schedules are present (World Health Organization 2004).

1.2.3.1 Sleep problems during adolescence

Adequate sleep is an important factor for health and health- related behaviors. During sleep the body and nervous system can recuperate(Chen, Wang & Jeng 2006). While changes in the sleep structure are included in the adolescental development, most of the youth accumulate a significant sleep debt. Sleepiness linearly arises as the amount of sleep time decreases. This reverse ratio results in poorer school achievement, less sense of feeling good, frequent illness, icreased anger and lower levels of school enjoyment (Drake C et al. 2003) in {{32 Colrain IM ;}}. Insufficient sleep may be caused by intrinsic (circadian or homeostatic changes) and extrinsic (school starting time, social environment, academic pressure) factors. (LeBourgeois et al. 2005) for example reported on a multidimensional relation between environment, biology and sleep: sleep quality depends on internal factors (biology, health, psychosociology), as well on external factors (family, environment and culture). Sleep loss is a common problem during adolescence that leads to fatigue during daytime: 20- 50% of children and adolescents suffer from sleepiness during day time(Dewald et al. 2010).

Epidemiologic studies (Mindell, Owens & Carskadon 1999, Iglowstein I et al. 2003) have demonstrated a high prevalence of sleep disturbances ranging from night wakings or difficulties in falling asleep to medically or biologically based disorders. Insomnia, daytime sleepiness and other reported sleep problems affect about 10 to 30% school-aged children and adolescents (Hoban TF 2010). A decreased sleep efficacy and quantity are linked to following problems: sleepiness during school, reduced academic functioning, attentional difficulties and increased absence. Insufficient sleep results in deficits of psychological, behavioral and somatic skills leading to a prevalance of stimulant use (caffeine, nicotine) (LeBourgeois et al. 2005).

Inadequate sleep quantity or even a chronic sleep deprivation is getting to be a global problem in the next few years, because adolescents do not reach the recommanded amount of sleep (8-

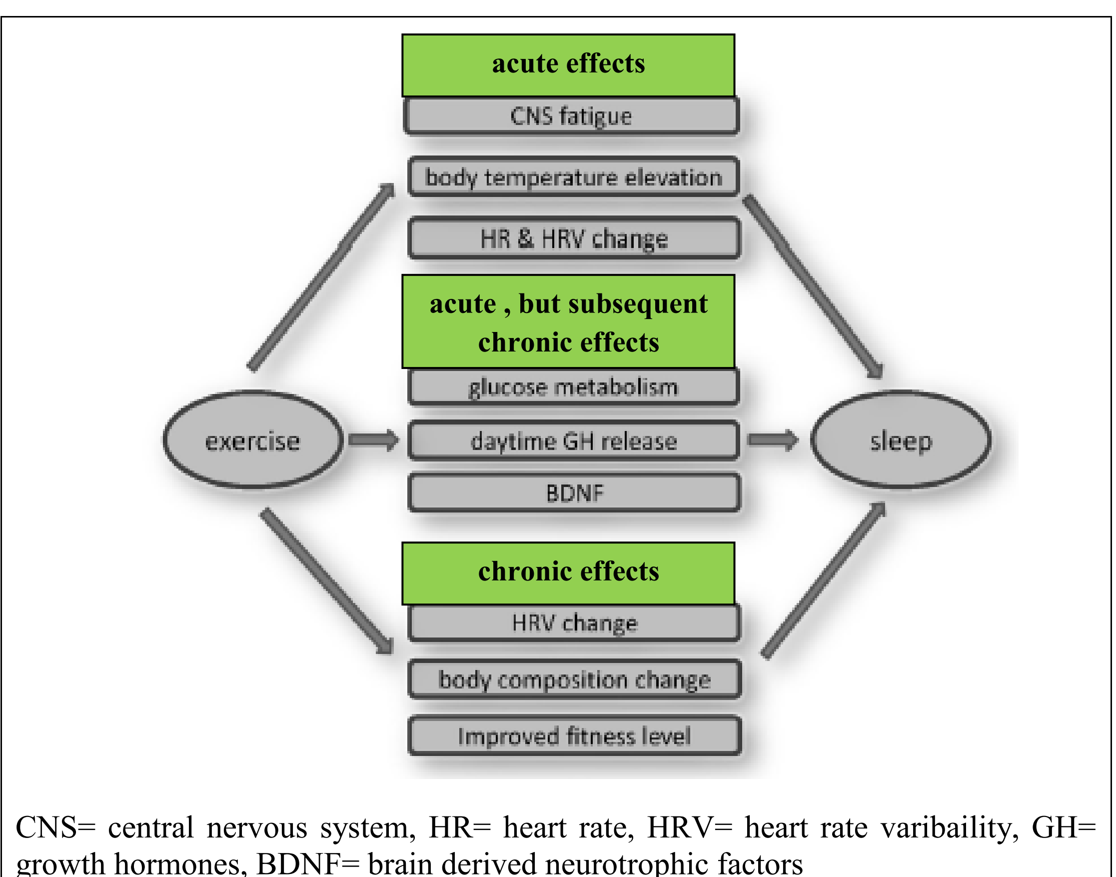
9 hours). Particularly, during school periods short nights are very common, because the compensation of sleep loss undergoes the academic achievement (Loessl et al. 2008).

However, the effects of inadequate sleep on the health status of adolescents remain unclear (Chen, Wang & Jeng 2006), because there is a lack of existing knowledge. Some studies focus on the relationship between sleep habits and sleepiness (Millman, Working Group on Sleepiness in Adolescents/Young Adults & AAP Committee on Adolescence 2005, Lewandowski, Toliver-Sokol & Palermo 2011), others report on the consequences of decreased sleep quality or quantity or even deprivation (Kelman 1999, Carskadon 2011). Current literature (LeBourgeois et al. 2005, National Sleep Foundation 2000) suggests that academic, emotional, health and behavioral problems may be mediated by interventional sleep hygiene. As adolesence is an crucial period for seeding all values and habits that will shape the whole lifespan it is so much the most important to find ways or interventions for an improvement of sleep patterns.

1.3 Effects of Physical Activity on sleep quality

Current reviews (Youngstedt, O'Connor & Dishman 1997, Driver, Taylor 2000, Atkinson G, Davenne D 2007, Uchida et al. 2012) confirm the positive relationship between regular physical activity and good sleep quality in healthy adults. Associations between physical activity and sleep include increases in total sleep time, higher sleep efficiency, less waking up and decreases in REM sleep periods. Research has especially focused on the effects of physical activity on sleep quality in healthy good sleepers with regard to physiological processes:

(Uchida et al. 2012)classified the effects of physical activity into “acute” and “chronic” components and components “arising after patterns of chronic exercise”. Figure 9 demonstrates the actute effects including the central nervous system (CNS), body temperature (BT) and autonomic modulation with heart rate (HR) and heart rate variability (HRV), the acute, but subsequent chronic effects involving the metabolic and endocrine components and the chronic effects that appear due to a change in body composition and fitness level.



CNS= central nervous system, HR= heart rate, HRV= heart rate varibaility, GH= growth hormones, BDNF= brain derived neurotrophic factors

Figure 9: Possible effects of exercise on sleep quality with the classification into acute, acute but subsequent chronic and chronic components, adapted from (Uchida et al. 2012, p.48)

The figure shows that the homeostatic sleep regulation is dependent from CNS fatigue with autonomic modulation, metabolic functioning with growth hormones release (GH) and brain derived neurotrophic factors (BDNF) and the fitnesslevel including the body composition and HR values. There is evidence that exercise could be a stimulus for auto-regulatory of the CNS, sustaining complex physiological mechanisms during the homeostatic cycling between wakefulness and sleep.

The review of (Driver, Taylor 2000) especially focused on the relationsship betweeen physical activity and the functions of sleep. It is obvious that exercise raises body temperature, therefore the body is exposed to a thermal challenge during day that sustains the ability to thermoregulate during sleep. There is evidence that those temperature effects may play a role in sleep regulation , especially in poor sleepers. The restorative function of sleep can also be optimzied by physical activity as anabolic activity during sleep is favoured through catabolic output during day. It is known that the sleep duration and the amount of SWS increase due to a higher energy expenditure through exercise. (Driver, Taylor 2000) also classified the effects of exercise in “acute” and “chronic” components:
Acute consequents of physical activity implicate the intensity, the type and the timing as important factors to the sleep response. It is suggested that exercise should be executed about 5 to 6 h before bedtime in order to guarantee a benefical effect. Meta-analysis with different study protocols and a lack of consensus make it difficult to find the optimal sleep enhancing intensity. However, there is evidence that moderate to vigorous intensity physical activity increases SWS, reduces REM sleep and delayes REM latency. The optimal duration is more than 1h of aerobic activity for acute effects on sleep quality.
The chronic component of exercise refers to an improved cardiorespiratory fitness that may have influence on sleep quality. Further research is needed, because it remains unclear whether a good fitness profile per se or other factors contribute to a better sleep architecture.

(Atkinson G, Davenne D 2007) reviewed the relationship between physical activity and sleep quality with the special focus on chronobiology and its circadian rhythmicity. The benefits of exercise on sleep include the energy conservation and restitution theory, as well the thermoregulatory response to exercise. They have suggested to concentrate more on the melatonine responses and to measure the range of core and distal body temperature changes in further studies. Also the circadian variations in blood pressure should be taken into consideration for the timing of physical activity.

It is obvious that physical activity nearly affect each system of the body, including cardiovascular, pulmonary, metabolic and endocrine functions[6]. The measurement of cardiovascular parameters with the focus on the ANS is of great interest in sport-scientific research, especially to get information about the trainings load. (Hautala, Kiviniemi & Tulppo 2009) reviewed the acute and chronic processes before, during and after aerobic exercise and demonstrated that the assessment of ANS activity through HRV is a good indicator for trainings response. The main findings suggested that good aerobic capacity was related to a high vagal outflow of HR and that the ANS adaption to sportive stimuli showed a decrease of HR during rest, mediated by changes in the ANS and instrinsic properties of the heart. (Sandercock, Bromley & Brodie 2005) examined the training effects on HRV parameters in a meta-analyses of 25 studies during day and came to the conclusion that 4 weeks of training were long enough to see chronic effects of exercise in cardio- autonomic parameters; especially young subjects showed the largest increase in RR intervals without a significant increase of vagal components (HF power).

Taken together, the balance of the ANS is influenced by a higher vagal modualtion and a lower HR during day, but the ANS response to sportive stimuli during sleep has not been well established.

As sleep is modulated by autonomic functioning, it is assumed that there must be a bidirect relation between exercise and sleep: in fact, this relationship between physical activity and sleep, regulated through the ANS exists. There is evidence (Uchida et al. 2012, Hautala, Kiviniemi & Tulppo 2009, Hynynen et al. 2008, Nummela et al. 2010, Hynynen et al. 2010) that the autonomic modulation during sleep can be influenced by daytime exercise, although precise information on nocturnal HRV parameters is still lacking.

(Hynynen et al. 2010) reported on changes in nocturnal HRV parameters after a 33 weeks intervention (7+- 2 hours per week) in 10 healthy physical active men; changes in nocturnal heart rate and parameters of HRV give information on the extent of exercise-induced autonomic regulation. A decrease in HRV and increase in HR after a marathon and even after moderate exercise could be observed, indicating that exercise has an impact on the homeostasis during the succeeding night sleep; this reaction of the ANS could be classified as "acute" effect. Another finding showed that the higher the HF values in non-stressed conditions, the greater the response after exercise sessions supporting the "autonomic

[6] The influence of physical activity on the body can be found on page

resource hypothesis": the adaptability of the ANS varied between humans as a function to resources.
The chronic impact of the training on autonomic modulation during night was demonstrated in the investigation of (Nummela et al. 2010). They found out in 24 sedentary adults that especially the nocturnal vagal component (changes in HF power) was enhanced after a 4-weeks moderate intevention program (2 hours per week).
The optimal intensity of physical activity for enhancing sleep remains still unclear. (Myllymaki et al. 2012) investigated the effects of duration and intensity on HRV indicis during sleep, as well as on actigraphic and subjective sleep quality in 14 healthy male subjects. The results showed that increased exercise intensity augmented HR during sleep, but did not change HRV parameters. Increased intensity and duration may alter the autonomic modulation, but did not affect the sleep quality objectively measured by actigraphs and self-reported (questionnaires).
The nocturnal response of the ANS on exercise in children and adolescents is very similar to adults, although reference values are still lacking in current literature. The investigation of (Mandigout et al. 2002) e.g. evaluated the effects of an endurance intervention on HRV parameters in prepubertal children during sleep and further focused on the realtion between HRV and training induced cardiac morphological and diastolic adaptions. After 13 weeks the aerobic capacity was significantly increased and an improvement of morphological, functional and cardia parameters within the nocturnal HRV was observed. No alteration of the sympathetic-parasympathetic balance could be demonstared.

Table 4 summarizes the mentioned investigations on autonomic adaptions during sleep in response to physical activity. Sport-scientific research is focused on HRV parameters during day, however, there is a lack of studies with HRV indices during sleep.

Table 4: Main findings of the relationship between autonomic modulation during sleep and physical activity in adults and children

Reference	Sample	Study Design	Target	Intervention	Measurement	Results
(Hynynen et al. 2010)	10 healthy men, mean age= 37 ± 5 years	Intervention study for 33 weeks	Effects of endurance exercise on nocturnal autonomic modulation	Trainings-amplitude: 5 ± 1 times per week and 7 ± 2 h per week for 33 weeks.	Nocturnal R-R intervals were collected after a rest day, after a moderate endurance exercise and after a marathon	SD of R-R intervals decreased to 90 ± 9 % and 64 ± 10 % , root-mean-square of differences between adjacent R-R intervals to 87 ± 10 % and 55 ± 16 % , and high frequency power to 77 ± 19 % and 34 ± 19 % of baseline after moderate endurance exercise and marathon, respectively. LF power decreased to 56 ± 26 % of baseline after the marathon.
(Nummela et al. 2010)	24 sedentary adults	Intervention study for 4 weeks	Effects of endurance training on cardiac autonomic modulation during night sleep	Trainings-amplitude: 2 h per week with 76 ± 4 % of HRR for 4 weeks	R-R intervals and HRV with HF power were calculated for the nights following the training days every week.	Nocturnal HFP was significantly higher during the fourth training week compared to the first training week ($p = 0.036$). Significant correlation between the change in v max and the change in nocturnal HFP ($r = 0.482$, $p = 0.042$).

(Myllymaki et al. 2012)	14 healthy male subjects, mean age 36 ±4 years	Exercise testing	Effects of exercise intensity and duration on nocturnal HRV-based relaxation, as well as on actigraphic and subjective sleep quality	5 different running exercises on separate occasions: effect of intensity was studied with 30 min of exercises at 45% (easy), 60% (moderate) and 75% (vigorous) of VO2max; effect of duration was studied with 30, 60, and 90 min of moderate exercises	Nocturnal HR and HRV	Increased exercise intensity elevated nocturnal HR compared to control day ($p < 0.001$), but did not affect nocturnal HRV, nocturnal HR was greater after the day with 90- than 30- or 60-min exercises ($p < 0.01$) or control day ($p < 0.001$); no impact on actigraphic or subjective sleep quality.
(Mandigout et al. 2002)	19 prepuberta l children, mean age= 10–11 years	Intervention study for 13 weeks	Effects of an endurance training program on nocturnal HRV and the relationships between time and frequency domains of HRV and training-induced cardiac morphological and diastolic function adaptations.	13-week endurance training program (3 x 1 h per week with an intensity, > 80% HRmax	Before and after the intervention: VO_{2max}, HRV of 5 h night ECG recordings, and left ventricular (LV) cardiac morphology and function	Increase of $V O_{2max}$ ($p < 0{\cdot}01$) after the training program, of all frequency domain components except low (LF) to high (HF) ratio. For the time domain components, increase of N–N intervals

In conclusion there is evidence that physcial activity helps promoting sufficient sleep although details about the relation of intensity, duration, frequency and especially the timing on sleep patterns like quality, latency, duration and daily sleepiness remain not clear. Most studies focused on healthy good sleepers limiting the improvements of sleep quality itself. In current literature the relationsship between exercise and the functions of sleep is more predominant than the efficacy of physical activity for enhancing sleep. There is a lack of studies with children and adolescents, especially invetsigations of autonomic modulation during sleep after physical activity are missing. The demand of further studies with comperable methodology and higher sample sizes is apperent as objective data on the relationsship of physical activity and sleep related components are still lacking.

1.4 Aims and research questions

Human sleep follows a circadian rhythmicity that is synchronized to interne as well externe stimuli. Externe stressors like physical activiy stimulate the whole bodily system and particularly leave physiological changes in the autonomic nervous system (ANS), especially during sleep. The impact of exercise on sleep patterns include acute and chronic effects with main changes in metabolic and autonomic functioning.
For this study the autonomic influence of physical activity on sleep quality is of further interest and can be measured by heart rate variability reflecting the autonomic nervous system. Due to easy derivation and non- invasivity, HRV measurements are the golden standard among ANS assessements, because they easily offer an additional insight into physiological conditions with sympathetic and parasympathetic modulation.

As current literature about the relationsship between physcial activity and sleep architecture in adolescents is scarce, investigations with pupils in the field of sleep medicine have a high prevalence. In addition the high evidence of sleep problems among teenagers demands for strategies that enhance the sleep quality, efficiency and recovery.

The main aim of this study was to examine the effect of two types of intervention (vigorous-intensity jogging vs. coordination training) on the autonomic sleep recovery in female adolescents pupils (N= 31) measured by heart rate variability. The study was conducted to get possible answers to following research questions:

A. Characteristic of physical activity:

Does the intervention program (coordinative group) increase the fitness of the pupils, measured by the shuttle run test?

Does the intervention program (jogging group) increase the fitness of the pupils?

Does a better fitness profile after the intervention contribute to a change in autonomic modulation?

B. Characteristic of autonomic sleep quality:

Does physical activity influence the autonomic nervous system during night?

Is there an improvement of autonomic sleep quality during the intervention period in both groups?

Do the two types of physical activity differ in their impact on the autonomic sleep recovery?

Does the interim between pre- to intervention period show a significant reaction of HRV parameters?

Providing an improvement of the autonomic sleep quality during the intervention period is sustainability achieved in the post period?

Do the HRV indices return to the basal level after the intervention?

C Characteristic of well- being:

Does the intervention program of the coordinative group influence the pupils´ well-being?

Does the intervention program of the jogging group influence the pupils´ well-being?

D Relationship between questionnaires and objective measurements

Is there a relationship between the cardio- autonomic parameters and the subjective sleep quality?

2 Methods and Hypothesis

2.1 Participants

The study included 31 female pupils from the city of Graz (Austria) attending the private college Sacrè Coeur. Their age ranged from 13 to 15 years with a mean of 14.00 years. All pupils were physically healthy and were medication-free for at least three months before the investigation. Major life events and participation in competitive high level sportive activity were exclusion criteria for all girls. Participants were recruited by a presentation at school and were well-informed about the study design, the interventions, and the measurements. The study was approved by the local ethics committee of the Medical University of Graz, Austria and a written informed consent was obtained from all participants and their parental authorities. They were told that they could withdraw from the study at any stage. Table 5 provides the demographic and fitness data for all participants.

Table 5: Demographic and fitness data of all participants (N= 31)

Variables	*Mean*	*SD*	*N*
Age (years)	13.97	0.48	31
Body height (m)	1.67	0.05	31
Body weight (kg)	56.15	9.31	31
BMI (kg/m^2)	20.13	2.63	31
Number of cigarettes/week	1.13	3.34	31
Coups of caffeine/day	0.16	.37	31
Coups of alcohol/week	0.35	0.92	31
Duration of sports exercise/week (min)	172.42	140.68	31

Table 6 and Table 7 show the development of the sample size with regard to the psychological and physiological missing data (%)[7]. The person c11 quit the study during the first week and the person a10 gave up during week 5 because of personal reasons. The psychological data referred to all questionnaires and the physiological data just included the Sleep Quality Index (SQidx) within its Auto Chrone Image (ACI) valid. For analysis, we further had to exclude 3 people due to following reasons: Person a14 dropped out because of too many missing values. Participants a06 and c06 were excluded because they did not show at least one valid SQidx in each period. The final sample for statistical analysis consisted of twenty-six girls.

[7] Especially the missing values accounted for the drop out quote

Table 6: Sample space of all participants (N=31) during week 1- week 4 with an itemization of psychological and physiological data

			psychological data		physiological data			
							2 recordings missing	ACI valid
PRE-PERIOD W1		3	questionnaires missing	5	SQidx missing	ill	a14	c01 (96,2)(48,2) fault 0-6 h
N= 31			a14, c10, c11		a10, a14, c01, c03, c11	fault	a10	c03 (64) (41,7)
						drop out	c11	
	Missing in %		9,7		16,1			
↓								
							2 recordings missing	ACI valid
PRE-PERIOD W2		1	questionnaire missing	6	SQidx missing	ill	a11	b03 (97,6)(60,3) fault 0-6 h
N= 30			a11		a11, a13, b03, b06, c06, c1	fault	a13	b06 (82,7)(42,3)
								c06 (86,8) (54,6)
								c10 (99,8)(72,2) fault 0-6 h
	Missing in %		3,3		20			

			psychological data		physiological data			
							0 recordings missing	ACI valid
INTERVENTION W3		0	questionnaire missing	3	SQidx missing			a06 (93,3)(49,8)
N= 30					a06, a14, c08			a14 no values during night
↓								c08 (96,2)(52,6) fault 4-7 h
	Missing in %		0		10			
INTERVENTION W4		5	questionnaires missing					
N= 30			a01, a10, a14, c05, c07					
	Missing in %		16,6					

Table 7: Sample space of all participants (N=31) during week 5- week 8 with an itemization of psychological and physiological data

	psychological data		physiological data				
					2	recordings missing	ACI valid
INTERVENTION W5 N= 30	2	questionnaires missing		SQidx missing	fault	a14	a06 (85,6)(47,4)
		a10, c04	10	a06, a09, a10, a14, b02	drop out	a10	a09 (99,2) (75,7) fault 0-6 h
				b04, b06, c01, c03, c06			b02 (95,4) (74,6)
							b04 (90,6) (53,7)
							b06 (95,5) (70)
↓							c01 (99,3) (92,3)
							c03 fault 16-24h
							c06 76 (7,21) fault during night
Missing in %		6,7		33,3			
INTERVENTION W6 N= 29	1	questionnaire missing					
		a14					

	psychological data		physiological data				
					2	recordings missing	ACI valid
POST-PERIOD W7 N= 29	2	questionnaires missing	6	SQidx missing	ill	c06, a12	a06 (80,8)(44,1)
		a12, c06		a06, a12, a14, c06, c09, c10			a14 fault during night
							c09 (93,3)(45,9)
							c10 (84,8)(47,1)
Missing in %		6,9		20,7			
↓							
					2	recordings missing	ACI valid
POST-PERIOD W8 N= 29	3	questionnaires missing	6	SQidx missing	ill	a04, a10	a02 (95,2)(66,1)
		a04, a14, c06		a02, a03, a04, b03, c06, c07,			a03 (98,3)(75) fault 2-6 h
↓							b03 fault during night
							c07 (99) (50,1) fault 22-10 h
Missing in %		10,34		20,7			
for analysis N= 26	→	3	drop out				
			a14	too many missing data			
			a06, c06	less than 1 value of SQidx in each period			

Both tables provide information on the collected psychological and physiological data. Missing questionnaires or HRV measurements were calculated in % in relation to the total amount of the participants for each week. The SQidx missings include non-conducted measurements or measurements with a low ACI valid indicating that the quality of the night records was not high enough for analysis. The second value of ACI, with its maximal value of 100, demonstrates the efficacy of the SQidx

2.2 Study Design

This study used a parallel pre-post design. The aim of this study was to examine the impact of two types of intervention (jogging vs. coordination training with vigorous intensity) on the autonomic sleep recovery in female pupils (N=31) and to analyse possibly different influences on the autonomic modulation. Pupils were not randomly assigned to guarantee a low dropout rate but they were able to choose between the coordinative or jogging training before the start of the intervention. The study (Table 8) lasted 8 weeks and was split up into pre (w1, w2), intervention (w3, w4, w5, w6), and post (w7, w8) periods. The study was described in greater detail at a formal meeting at school and all pupils were allowed to ask questions. They were told they would be paid a modest sum at the end of the study for their participation and were given informed consent forms to review. Their parents' signatures were required. Before beginning the study, the protocol and the consent forms were approved by the Medical University of Graz.

Table 8: Experimental design over 8 weeks with N= 31

<table>
<tr><td>Weeks</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr>
<tr><td>Periods</td><td colspan="2">PRE</td><td colspan="4">SPORTINTERVENTION</td><td colspan="2">POST</td></tr>
<tr><td>Sample size</td><td colspan="8">N 31</td></tr>
<tr><td rowspan="2">Groups</td><td colspan="8">coordinative group (N = 16)</td></tr>
<tr><td colspan="8">jogging group (N = 15)</td></tr>
<tr><td>Methods</td><td colspan="2">HRV, sr, QU</td><td colspan="4">HRV, QU</td><td colspan="2">HRV, sr, QU</td></tr>
</table>

HRV= measurement of heart rate variability; sr = shuttle run; QU= psychological questionnaires

The table below shows the testing variables.

Table 9: Measured variables over a period of 8 weeks in a sample of N= 31

		graduation
Independent Variables	Period of time	6-fold
	Intervention group	2-fold
Dependent Variables	Results from physiological, psychological and sport scientific data analysis	

Note: The dependent variables represent the results from HRV-, shuttle-run measurements and subscales of the psychological questionnaires.

The Pre Period

The pre period (w1, w2), included two 24-ECG measurements, standardised psychological questionnaires, and a standardised fitness test (shuttle run) to quantify the fitness level of the pupils. Before starting the measurements, detailed recordings about the participants' characteristics and their menstruation cycle were undertaken. Information about socio-demographics, leisure time behaviour and health status were answered by all participants. The first HRV measurement in week 1 was a test measurement to ensure good reproducibility in the following physiological measurements and will not be mentioned in the result chapter.

The Intervention Period

The intervention period (w3, w4, w5, w6) lasted four weeks and was split up into two different interventions: one jogging and one coordinative training with vigorous intensity. The sport interventions took place simultaneously, three times a week for 30 minutes. 24h-ECG-measurements were carried out twice and the standardised questionnaires were answered four times.

The Post Period

The post period (w7, w8) lasted two weeks and was structurally identical to the pre period. Two 24-ECG measurements, standardised questionnaires, and the shuttle run test were conducted.

2.3 Measurements

The method of collecting data can be divided into three major fields: physiological (HRV measurements), fitness-related (shuttle run test), and psychological measures (standardised questionnaires: PSQI, HRI, IPAQ, BSKE, EBF, MKSL)

2.3.1 Time of Measurements

Table 10 shows the time of measurements over 8 weeks, where five regular points of physiological measurements (w2, w3, w5, w7, w8) were arranged after the test measurement in the first week (w1). It also shows that two shuttle run tests (w2, w7) were conducted and eight measure-diaries with psychological questionnaires and activity protocols (w1-w8) were carried out. In order to maintain the circadian rhythm of all participants, the same location, the same days of the week (Tuesday/Wednesday/Thursday), and the exact starting time of the ECG-measurements (7.45 am) were ensured.

Table 10: Time of all measurements during 8 weeks

Weeks	1	2	3	4	5	6	7	8
Periods	PRE		SPORTINTERVENTION				POST	
Basic recordings								
Shuttle run test		m1					m2	
HRV	TEST	m1	m2		m3		m4	m5
Questionnaires	m1	m2	m3	m4	m5	m6	m7	m8

m=measurement; HRV=heart rate variability

2.3.2 Physiological Measures

Heart Rate Variability

The heart rate is an important variable of a complex regulatory system, which is additionally influenced by temperature, breathing, blood pressure, and psych-mental circumstances. It leads to a typically temporal structure that is called heart rate variability (HRV).

Standards and physiological interpretations of HRV are described in the Task Force of the European Society of Cardiology (Task Force 1996). The arousal with its electrical potential divagations can be measured with an electrocardiogram (ECG) that subsumes the waves (P,

Q, R, S, T, U) to intervals with certain durations. The interval between two R-waves approximates one heart period, but does not appear in regular episodes. Those errors imposed by the imprecision of RR interval sequences assume an editing process. Editing should be performed at a high standard related to correct identification and classification of each QRS complex. For a valid and high qualitative analysis, an exact recognition of heart beats, a detection of artifacts, and a subsequent processing are preconditions (Grote et al. 2011).

The heart rate variability (HRV) was exactly determined with the ChronoChord (

Figure 10) that has been specialized in high-resolution recordings of heart beat intervals (RR intervals). It was developed by the Institute of “Human Research” (Institut für Gesundheitstechnologie und Präventionsforschung) in Weiz, following the technologies of the space project “AustroMir” (Moser et al. 1992)and approved under CE regulations.

Figure 10: ChronoChord records heart rate and respiratory correlated parameters over 24-hours with a high standard of RR identification

The figure shows the ChronoChord, an invasive method for assessing HRV. This measurement was suitable for mobile recording of the functional autonomous regulation and enabled a 24-hour monitoring of heart rhythm.

Cardiac autonomic modulation was assessed by HRV analysis of 5-minute RR intervals, analysed by time and frequency methods. Time-domain was analysed by standard deviation of the RR intervals and the root mean square of successive differences of RR intervals. The power spectral components were seen at low and high frequencies. Twenty physiological

parameters during work and rest could be analysed with the software MATLAB®. To guarantee faultless inter-beat intervals, the identification of R-peaks was supported with recognition of artifacts. An interpolation method for completing the missing signal episodes was used. This process was necessary if less than 5% of the temporal intervals were defective. Otherwise, a missing value would appear. For the frequency domain the inter-beat interval was converted to a time-domain interval (Moser et al. 1994, Moser et al. 2005).

The most important parameters in the time-domain are mentioned below (Grote et al. 2011, Moser et al. 2005) (Grote et al. 2011, Moser et al. 2005):

Standard deviation of RR-intervals (SDNN) [ms]: standard deviation of RR-intervals over a time interval; total variability in time domain

Respiratory sinus arrhythmia (logRSA) [ms]: the respiratory sinus arrhythmia (RSA) is a high-frequency heart rate variability that reflects the modulation of heart rhythm through the respiratory system. Simultaneously, it is a measure for vagal activity.

Pulse-respiratory-quotient (PRQ)[-]: the pulse-respiratory-quotient shows the heartbeats during one breath; the relationship between heartbeats and the respiratory cycle.

The most important parameters in the frequency-domain are mentioned below:

Total frequency (TOT) (): power of the whole frequency domain from 0.033- 0.5 (Hz)

High Frequency (HF): the domain of HF includes fluctuations over periods from 2.5 to 7 seconds (0.15-0.4 Hz). It reflects the activity of the parasympathetic system and shows heart rate variations depending on the modulation of the respiratory system.

Low frequency (LF): the domain of LF includes fluctuations over periods from 7 to 25 seconds (0.04-0.15 Hz). It is influenced by the parasympathetic (deep breathing) and the sympathetic system. The low frequency of heart rate variability corresponds to the blood pressure rhythm with a frequency of about 0.1 Hz.

Vegetative quotient (VQ): The quotient of LF and HF gives information about the balance of the autonomic nervous system. High values show an active, high- performance phase of the body, low values represent relaxation.

Very low frequency (VLF): the domain of VLF includes fluctuations over periods of 0.0033-0.04 Hz.

Sleep quality index (SQidx): It is calculated from the heart rate (HR) and vegetative quotient (VQ). The duration of sleep will be provided for the total duration of measurement; this ratio serves as the threshold level of HR or VQ that can be over- or under-run. During sleep, a decrease of HR or VQ is beneficial for the body. The parameter SQidx shows the percentage (%) of this beneficial physiological performance during night. For example, the measurement lasts 24 hours with 8 hours of sleep and 16 hours of wakefulness. The threshold will be determined at 33.3% (8/24). Then, the value of HF is calculated, which divides the total value into 33.3 or 66.6%. This is the threshold value for HR; the aim of the SQidx is to analyse how often (%) this norm value of HR is underrun. Good and quiet sleep creates a low heart rate and a high vagal activation; theoretically, the SQidx should be 100%, indicating that during sleep, values of recovery are dominant that cannot be achieved during the day. Empirically, the norm value of SQidx (N=676) is up to 55% (Grote et al. 2011, Moser et al. 2005).

The Chronocardiogramm

The results were processed in a chronocardiogramm (previously known under: autochrone image (ACI) (Moser et al. 1999)), a depiction of all HRV parameters. Three signals in three different dimensions were represented (abscissa = time, ordinate = frequency, colour = amplitude). Each line was the result of the frequency analysis of a short time period; the amplitude of the signal was coloured. Blue meant low amplitude; conversely, red signified high amplitude. An image depending on rhythms in time was produced. Due to the time indices of RR intervals the resulting heart rate was determined and plays an important role for a further graphical processing. Figure 11 shows a chronocardiogramm.

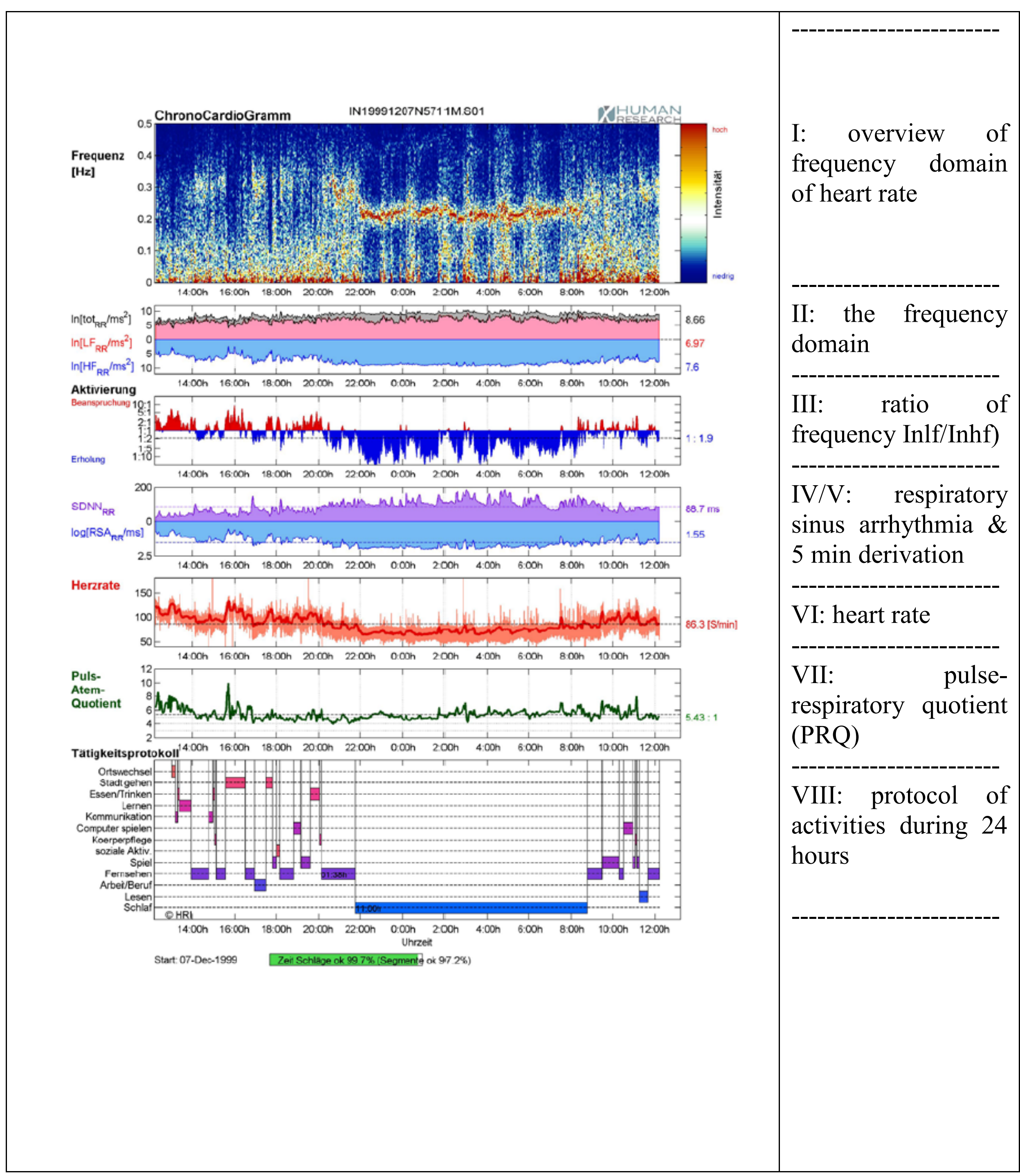


Figure 11: ChronoCardioGramm with 8 informative parts of HRV analysis

Ad I: The time domain will be converted to the frequency domain by the Fourier transformation. The transformation breaks the total signal of each sinus oscillation and depicts the normalcy of each frequency quotient.

Ad II: the frequency domain will be subdivided into three categories:

0.04 Hz- 0.15 Hz = Low Frequency (LF)~ sympathetic activation

0.15 Hz- 0.4 Hz = High Frequency (HF)~ vagal activation

0- 0.4 Hz= total variability

Ad III: The Vegetative Quotient (VQ) is the ratio from sympathetic to vagal activity and reflects the autonomic balance (explained on p.)

Ad IV: the respiratory sinus arrhythmia (RSA) is a high frequent heart rate variability that reflects the modulation of heart rhythm through the respiratory system and was further explained on page

Ad V: SDNN is the mean of one standard deviation of a RR- interval within a time domain.

Ad VI: The heart rate (HR) is calculated from the detected RR- intervals

Ad VII: the pulse-respiratory-quotient (PRQ) shows the heartbeats during one breath; the relationship between heartbeats and the respiratory cycle. The ratio 4: 1 (heart rate: respiratory rate) is an optimum and does exist during sleep

Ad VIII: the protocol of activities was filled in by all participants. The coloured background is dependent from the VQ.

Another example (Figure 12) shows the illustration of the ChronoCardioGramm that is exclusively calculated from the ECG and categorized after the sleep classification of Rechtschaffen and Kales.

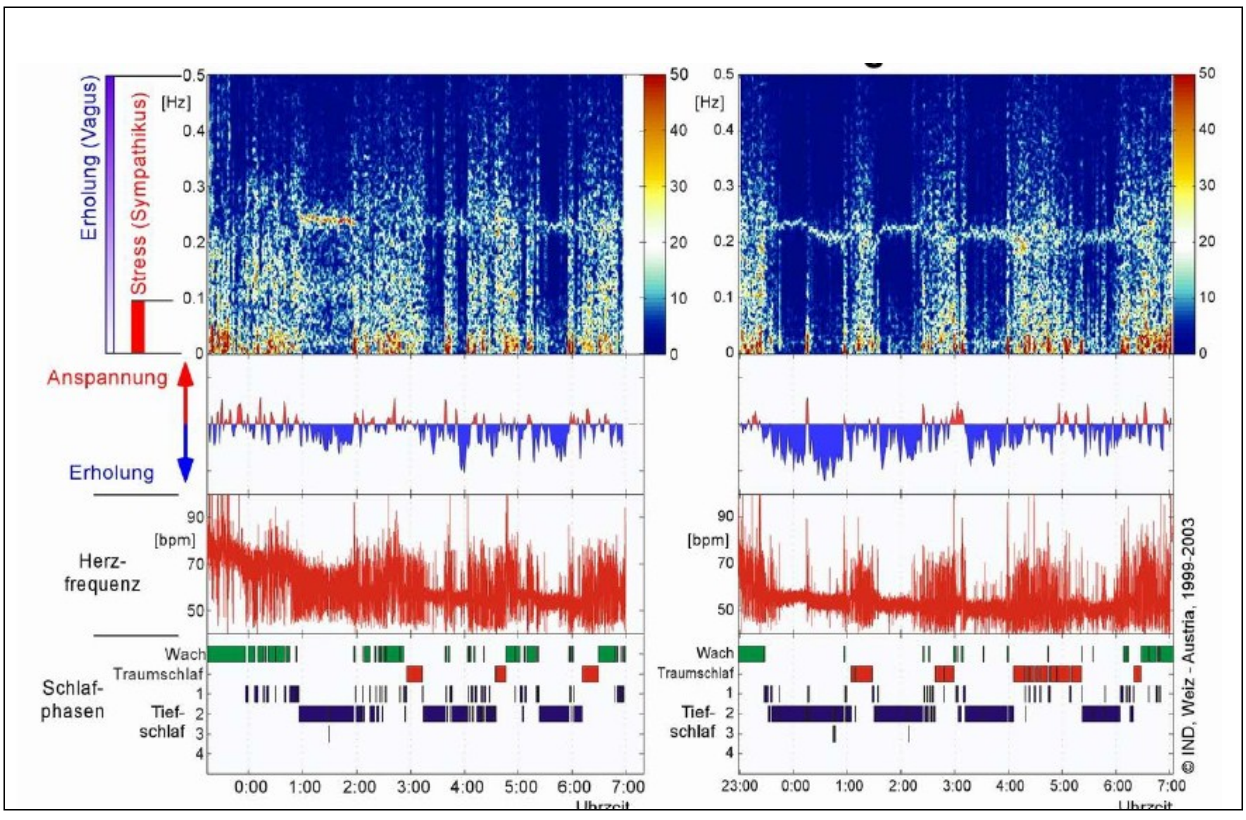


Figure 12: ChronoCardioGramm of a healthy young man during a bad night on the left side and a good night on the right side (data from University of Freiburg, Prof. Dr. Riemann)

Figure 12 shows the same person with poor sleep on the left side and with good sleep on the right side. Good sleep architecture runs cyclically with main differences between quiet sleep and REM cycles. On the right side, the vagal activation (second figure in blue) is much higher than on the left side.

2.3.3 Sport Scientific Measure

20 m Shuttle Run Test

The maximal multistage 20 m shuttle run test was chosen to determine the maximal aerobic power of all participants. In current literature, it is a widely used fitness test (good reproducibility, reliability and validity) because of a simple conduction with minimal equipment for many participants at once: all pupils ran back and forth on a 20-meter course, marked with caps on the final lines and had to touch the 20-meter line inside the gym; the running speed had to be assimilated to the sound signals that were simultaneously emitted from a CD-player setting the speed in advance. Frequency of the sound signals was constantly increased 0.5 km h-1 each minute after the set-off speed of 8.5 km h-1. When the pupils could no longer follow the pace, the last level and number of shuttles announced the shuttle run stage. This stage was used to predict maximal oxygen uptake (VO_{2max}) (ml.kg-1.min-1) with the formula of (Leger et al. 1988): "the last stage number announced is used to predict maximal oxygen uptake (VO_{2max}) (Y, ml kg-1 min-1) from the speed (X, km h-1) corresponding to that stage (speed = 8 + 0.5 stage no.) and age (A, year): Y = 31.025 + 3.238 X - 3.248A + 0.1536AX".

A classification (Table 11) in untrained, average and trained participants was conducted referring to normative values in current literature (Shvartz, Reibold 1990, Rodrigues et al. 2006).

Table 11: A classification of shuttle run stages in trained average and untrained among female adolescents

Stages of shuttle run	VO2max	classification
≤ 7	≤ 38	trained
6	33- 37.9	average
≥ 5	≥ 32.9	untrained

2.3.4 Psychological Measure

Each week the participants had to fill in a measure diary that included following questionnaires:

Effects were recorded in the morning or in the evening (Table 12) by means of self-rating questionnaires, regarding the pupils´ current subjective state and their judgement of the quality of sleep. With the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al. 1989) and the HRI (Grote 2009) the quality and patterns of sleep were collected. The measure diary also included a daily protocol where all activities were listed. The short version of the International Physical Activity Questionnaire (IPAQ) was used to obtain comparable estimates of physical activity (Hallal, Victora 2004). The self-rating was done by the Multidimensional Mood Inventory BSKE (EWL) by (Janke, W. & Hüppe, M. 1996) and by the Multidimensional Somatic Symptom List (Erdmann, Janke 1984). The amount of experienced stress and recovery was assessed with Kallus' recovery-stress questionnaire (Kallus 1995), a version designed for pupils. All questionnaires are added in the appendix.

Table 12: Time of measurements of all questionnaires during 8 weeks in a sample of N= 31

	W1	W2	W3	W4	W5	W6	W7	W8
PSQI								
HRI								
AP*								
IPAQ								
BSKE								
MKSL								
EBF								

in the morning of 24- hours measurement	during the 24- hours measurement
in the evening of 24-hours measurement	at the beginning of 24- hours measurement

*AP= activity protocol

This table shows the time of measurement of all psychological questionnaires with four possibilities: in the morning, in the evening, during or at the beginning of the 24 hours measurement.

Activity Protocol

For a better interpretation of 25-hour ECG files, all participants had to fill in an activity protocol (Table 12). This activity protocol required the code of the participant, the date and time of measurement and a numeration of all activities over the whole day. Different categories of daily activity were listed with a number. The participant was able to choose a number for the activity instead of writing down long explanations. If a special activity with its number was missing, the participant had the opportunity to note that. The results are not similarly analysed, they just serve as control.

Table 13: Activity protocol for the whole day during HRV measurements

Uhrzeit		Code[1]	2	Bemerkungen/Spezifizierung[3]
Beginn	Ende		Liegen/Sitzen/Stehen	
				HeartMan einschalten (genaue Uhrzeit)

International Physical Activity Questionnaire (IPAQ)

In response to the global demand for comparable and valid measures of physical activity the International Physical Activity Questionnaire (IPAQ) was developed with a long form of 31 items and a short form of 9 items. As there is no difference between the reliability and validity of the short and long form, the short form was used. This questionnaire recorded activity of three intensity levels: vigorous intensity (8 METs), moderate intensity (4 METs) and walking (3,3 METs) (International Physical Activity Questionnaire). MET minutes per week were seen as duration x frequency per week in order to produce a total activity per week (Craig et al. 2003) (Hallal, Victora 2004).

Pittsburgh Sleep Quality Index (PSQI)

The Pittsburgh Sleep Quality Index (PSQI) is a self-rated questionnaire that assesses subjective sleep quality. Nineteen individual items generate the following scores: subjective

sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction (subjektive Schlafqualität, Schlaflatenz, Schlafdauer, Schlafeffizienz, Schlafstörungen, Schlafmittelkonsum, Tagesmüdigkeit)[8]. The sum of scores for these seven components yields one global score. The scale (0 to 3) represents the scoring of answers. A cut-off value of 5 or greater indicates a poor sleeper, less than 5 a good sleeper (Buysse et al. 1989).

HRI sleep

The HRI-sleep is a self-rated questionnaire that assesses actual sleep quality. Seven individual items generate the global sleep recovery: subjective sleep quality, sleep latency, sleep duration, sleep efficacy, quality of awakens, sleep continuity, sleep deficit (subjektive Schlafqualität, Schlaflatenz, Schlafdauer, Schlafeffizienz, Aufwachqualität, Schlafkontinuität, Schlafdefizit). The analysis of all dimensions is automatized, but individual profiles can also be generated. The HRI was developed for healthy people. Enough values for file standards and an external validation do exist (Grote 2009).

Erholungs-Belastungs-Fragebogen (EBF)

The EBF identifies children´s current recovery-stress state, focusing on stress and its consequences during the last three days. The EBF-40/7-JK is an assessment for measuring children's current level of stress and recovery during the last three days. The EBF-40/7-KJ, based on the version for adults consists of 40 items (
Figure 13), which can be summarized into a global "recovery-stress-state" as well as into ten subscales named general stress, emotional stress, social stress, over-fatigue, social recovery, corporal recovery, general recovery, restorative sleep, exhaustion, performance at school (allgemeine Beanspruchung, emotionale Beanspruchung, soziale Beanspruchung, Übermüdung, Erholung im sozialen Bereich, körperliche Erholung, allgemeine Erholung, erholsamer Schlaf, Erschöpfung, schulische Wirkungsüberzeugung). Scoring of answers is based on a 0 to 6 scale; 0 represents "never" and 6 means "always" (Kallus 1995).

[8] As the original version of the questionnaires is mostly written in German, the name of the subtests are taken in German without translation in the result chapter

In den letzten 7 Tagen/Nächten ...

01) ... habe ich ferngesehen						
0 nie	1 selten	2 manchmal	3 mehrmals	4 oft	5 sehr oft	6 immerzu

02) ... hat mich die Schule stark ermüdet						
0 nie	1 selten	2 manchmal	3 mehrmals	4 oft	5 sehr oft	6 immerzu

03) ... hatte ich unangenehme Dinge zu erledigen						
0 nie	1 selten	2 manchmal	3 mehrmals	4 oft	5 sehr oft	6 immerzu

Figure 13: Example items of the EBF questionnaire

Mehrdimensionale Körperliche Symptomliste (MKSL)

The questionnaire "Mehrdimensionale Körperliche Symptomliste" (MKSL 20) is a tool to evaluate the actual corporal and mental state. The intensity of different symptoms should be pointed out on a six-fold scale (Figure 14). The scales refer to physical symptoms of stress (headache, mouth-dryness…) and relaxation (feeling of warm extremities, steady pulse…): cholinergic, vegetative and adrenergic symptoms and relaxation (Erdmann, Janke 1984).

Schmerzen im Nacken/Schulter						
0 überhaupt nicht	1 sehr schwach	2 schwach	3 etwas	4 ziemlich	5 stark	6 sehr stark

Figure 14: An example item of the MKSL questionnaire

Befindlichkeitsskalierung durch Kategorien und Eigenschaftswörter (BSKE)

The questionnaire BSKE is a tool to evaluate the actual mental state. The more dimensional scaling consists of different adjectives that describe emotional aspects of the actual psychological and physical state (figure 6). This instrument consists of 24 items and eight main scales: balance, mood, perceptual vigilance, infuriation, petulance, anxiety, perceptual anti-vigilance, intro/extroversion (Ausgeglichenheit, Stimmung, Aktiviertheit, Erregtheit, Gereiztheit, Ängstlichkeit, Desaktiviertheit, Extra/Introversion). These items generate two different scales: positive state or negative state (positives, negatives Befinden) (Janke, W. & Hüppe, M. 1996).

<u>1. Gefühl der inneren Erregtheit (z.B. aufgeregt, erregt)</u>

0	1	2	3	4	5	6
gar nicht	sehr schwach	schwach	etwas	ziemlich	stark	sehr stark

<u>2. Gefühl des seelischen Wohlbefindens (z.B. angenehm, zufrieden)</u>

0	1	2	3	4	5	6
gar nicht	sehr schwach	schwach	etwas	ziemlich	stark	sehr stark

Figure 15: Example items of the BSKE questionnaire

2.4 Intervention

The sport intervention was predefined as a vigorous, aerobic exercise trial 3 times per week for 30 minutes, split up in two groups. Both groups, a jogging and a coordinative group, were simultaneously trained with vigorous intensity at the same place and on the same days. Vigorous intensity was defined as an intensity of 65 to 85 per cent of the VO_{2max} or 70-90 per cent of HR_{max}; for determining the $HR_{max,}$ the age-predicted maximal heart rate formula (HR_{max}= 220-age) was used, which is a common method in scientific sport studies (American College of Sports Medicine 1995). During exercise, the heart rate was measured by the ChronoChord to control and ensure that the required exercise intensity was maintained. As it is not practicable to demand all girls to perform this training while strictly monitoring the heart rate, an additionally popular method was used for measuring exercise´s intensity. The "Talk Test" ensured that the girls worked out at a level, where they could carry on a conversation while breathing comfortably. (Persinger et al. 2004)found out that a comfortable conversation during exercise can predict an intensity of about 85% of the maximal heart rate.

Coordinative Group

An aerobics instructor was responsible for the coordinative training of 16 girls. Three times per week, the pupils took part in a little dance performance at a vigorous level of intensity for 30 minutes in the gym hall of Sacrè Coeur. The goal of this intervention was to improve the capacity of endurance and to stimulate the brain while stringing different moves together in a mixed-impact style. The pupils completed a training of 12 units for 30 minutes during 4 weeks.

Jogging Group

The training of the jogging group simultaneously took place with the other 15 girls and their three jogging trainers. Three running levels were offered to ensure the right velocity for the pupils with a different VO_2max values. The pupils completed a training of 12 units for 30 minutes during 4 weeks at vigorous intensity around the school district of the Sacrè Coeur, in the area of light traffic, green and housing areas. The goal of this intervention was to improve the capacity of endurance.

2.5 Statistical analysis

Physiological measures

The institute of “Gesundheitstechnologie und Präventionsforschung” in Weiz has developed algorithms for all parameters of heart rate variability. The analyses according to (Task Force 1996) were prepared by means of the software MATLAB. HRV was calculated from valid and visually inspected RR- intervals for time and frequency domain variables following a five minutes segment. 95% of the observed RR- intervals within the 5-minute periods had to be valid to get HRV-indices; otherwise the uncorrected and all other missing data in the statistical analysis were replaced by its mean values of all five measurements in SPSS. The level for statistical significance was determined as $p < 0.05$. The preconditions (metric data, normal distribution, homogenous variance) mostly exist. Data were analysed using SPSS version 18.0 (SPSS Inc., Chicago, IL.) for descriptive analyses. Slopes, intercepts, regression lines and correlation coefficients were calculated separately for both groups and the significance of differences was tested. The T-test was applied to test the significant differences of the regression lines. All parameters were operated through a repeated measures analysis of variance (ANOVA). All graphics were edited with Harvard Graphics to ensure high quality figures.

Psychological and Sport Scientific Measures

All psychological questionnaires were conducted with SPSS 18.0. The level for statistical significance was determined as $p < 0.05$. The preconditions (metric data, normal distribution, homogenous variance) mostly exist. All subtests were operated through a repeated measures analysis of variance (ANOVA) and were graphically presented by Harvard Graphics.

2.6 Hypotheses

A.) Characteristic of the autonomic sleep quality

Work-hypotheses:

A1: During the intervention period, the autonomic nervous system reacts on the induced stimulus of physical activity; this physiological process can be seen in different HRV parameters during night (dp: HRV parameters, id: time: 6- fold, ANOVA)

> A1.1: The interims between pre- to intervention period especially show ON effects of the training (dp: HRV parameters, id: time: 6- fold, ANOVA)

A2: The two types of training differ in their impact on nocturnal cardio-autonomic parameters during the intervention period (dp: HRV parameters, id1: time: 6- fold, id2: group, ANOVA)

> A2.1: The coordinative group achieves a higher level of vagal modulation and a lower profile of VQ than the jogging group during the intervention period (dp: HRV parameters, id1: time: 6- fold, id2: group, ANOVA)
>
> A2.2: Values of the HF/LF ratio differ in the groups during the intervention period (dp: HRV parameters, id1: time: 6- fold, id2: group, ANOVA)
>
> A.3.3: After the intervention period, autonomic balance returns to the basal level of autonomic sleep recovery (dp: HRV parameters, id1: time: 2- fold, id2: group, ANOVA)

A3: In both groups, the autonomic sleep quality increases during the intervention period (dp: HRV parameters, id1: time: 6- fold, id2: group, ANOVA)

> B3.1: The coordinative goup achieves a higher level of autonomic sleep recovery than the jogging group during the intervention period (dp: HFhf parameter, id1: time: 6- fold, id2: group, ANOVA)

B.) Characteristic of physical actvity:

Work-hypotheses:

B1: After 4 weeks of training with vigorous intensity, the girls´ fitness increases (dv[9]: shuttlerun, iv[10]: time- 2- fold, pre vs. post- t- test)

> A1.1: Both intervention programs make a contribution to a better profile of endurance seen in shuttle run values (dv: shuttle run, iv1: time- 2-fold, iv2: group, ANOVA)

---

[9] dv= dependent variable

[10] Iv= independent variable

B2: The untrained pupils especially reach one higher shuttle after the intervention period (dv: shuttlerun, iv: time: 2-fold, goup)

B3: 4 weeks with regular bouts of vigorous physical activity are enough to see changes in the cardio-autonomic profile during circadian variations (dv: HRV parameters during night, id: time: 6- fold, ANOVA)

A3.1: The two intervention programs have a different impact on cardio-autonomic parameters (dv: HRV parameters during night, id1: time: 6-fold, id2: group, ANOVA)

A4.1: The interims between pre- to intervention period especially show ON effects of the training (dp: HRV parameters, id: time: 6- fold, ANOVA)

C.) Accordance between qualitative and quantitative measures

Work-hypotheses:

C1: The outcomes of the subjective psychological sleeping parameters confirm the values of the cardio-autonomic parameters (dp1: HRV parameter, dp2: HRI-Schlaf, PSQI id1: time: 6-fold, id2: group, ANOVA)

C2: As the pupils hold a probably solid and normal psycho-mental profile, the impact on psycho-social and mental processes is little during the intervention period (dp: psychological questionnaires, id1: time: 8- fold, id2: group, ANOVA)

3 Results

The results follow a chronological order, starting with the physiological outcomes, continuing with sport scientific and ending with psychological results. The structure of this chapter complies with the order of the research questions and hypothesis.

3.1 Physiological parameters

3.1.1 Impact of physical activity on autonomic modulation during sleep

Heart rate (HR)

Descriptive values with their overall analysis are represented in Table 14, indicating a significant main effect (p=.050). Univariate analysis only showed a significant main effect (p=.045) in the jogging group.

Table 14: Descriptive values of the heart rate (HR) in a sample of N= 26 during sleep
(p: time=.050, time* group= .651, group=.123)

		m1	m2	m3	m4	m5
Jogging (N= 16)	mean	63,33	66,24	64,82	64,16	62,68
	SD	5,79	6,36	5,72	7,03	6,72
Coordinative (N=10)	mean	66,61	68,59	69,15	68,21	67,83
	SD	6,11	7,35	8,36	6,81	7,67

m1-m5: measurement 1- measurement 5; SD: standard deviation

Overall paired t-test comparisons revealed a significant increase between measurement 1 (m1) and m2 (p=.004) and a significant decrease between m2 and m5 (p=.029) in mean heart rate during sleep. However, univariate paired t-test comparisons showed a significant increase between m1 and m2 (p=.009) and a significant decrease between m2 and m5 (p=.008) in the jogging group. The coordinative group did not demonstrate any significance.

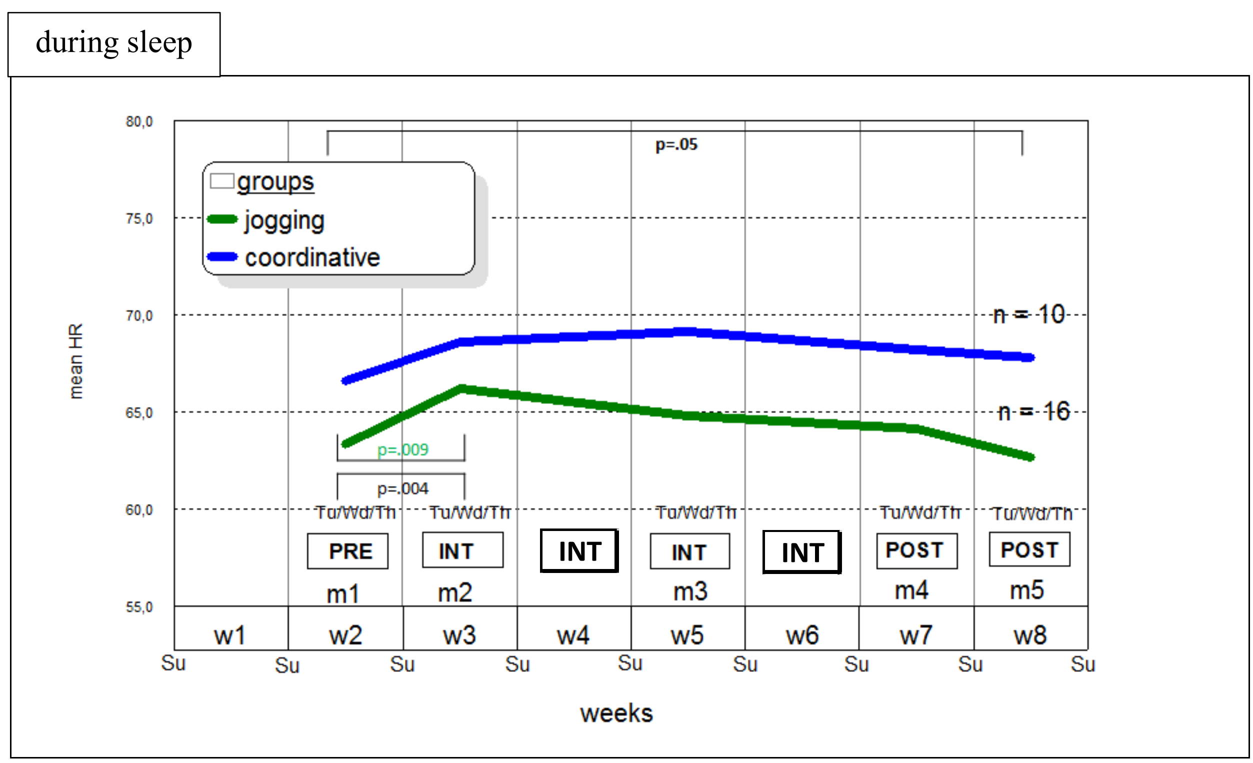


Figure 16: Development of the heart rate (HR) in a sample of N= 26 during sleep
Significant p-values of overall (in black) and univariate paired t-test comparisons (in colour)

Figure 16 shows the different compensation of both intervention groups during the night as a reaction to athletic stimuli. In the coordinative group, the heart rate increased (although statistically not significant) during the first week of intervention and the same level remained during the whole intervention period. In the jogging group, after a significant increase of the HR within the first week of the intervention, the HR significantly decreased until the end of the study.

Pulse-Respiratory Quotient (PRQ)

The Pulse-Respiratory Quotient (PRQ) is the ratio between heart rate and respiratory rate. Descriptive values with their overall analysis are represented in Table 15, revealing a significant main effect (p=.016). Univariate analysis only indicated a significant main effect in the jogging group (p=.014).

Table 15: Descriptive values of the Pulse-Respiratory Quotient (PRQ) in a sample of N= 26 during sleep
(p: time=.016, time*group= .747, group=.392)

		m1	m2	m3	m4	m5
Jogging (N= 16)	mean	3,88	4,06	4,07	3,88	3,88
	SD	0,56	0,71	0,63	0,57	0,7
Coordinative (N=10)	mean	4,09	4,23	4,18	4,14	4,12
	SD	0,51	0,52	0,51	0,45	0,5

m1-m5: measurement 1- measurement 5; SD: standard deviation

Overall paired t-test comparisons revealed a significant mean increase in Pulse-Respiratory Quotient between m1 and m2 (p=.028), m1 and m3 (p=.005), and a significant decrease between m3 and m5 (p=.032), as well as m2 and m5 (.030). Univariate paired t-test comparisons only showed a significant increase in the jogging group between m1 and m3 (p=.007) and a significant decrease between m2 and m5 (p=.019), between m3 and m4 (p=.029) and between m3 and m5 (p=.019). In contrast to the jogging group the coordinative group did not reveal mean differences.

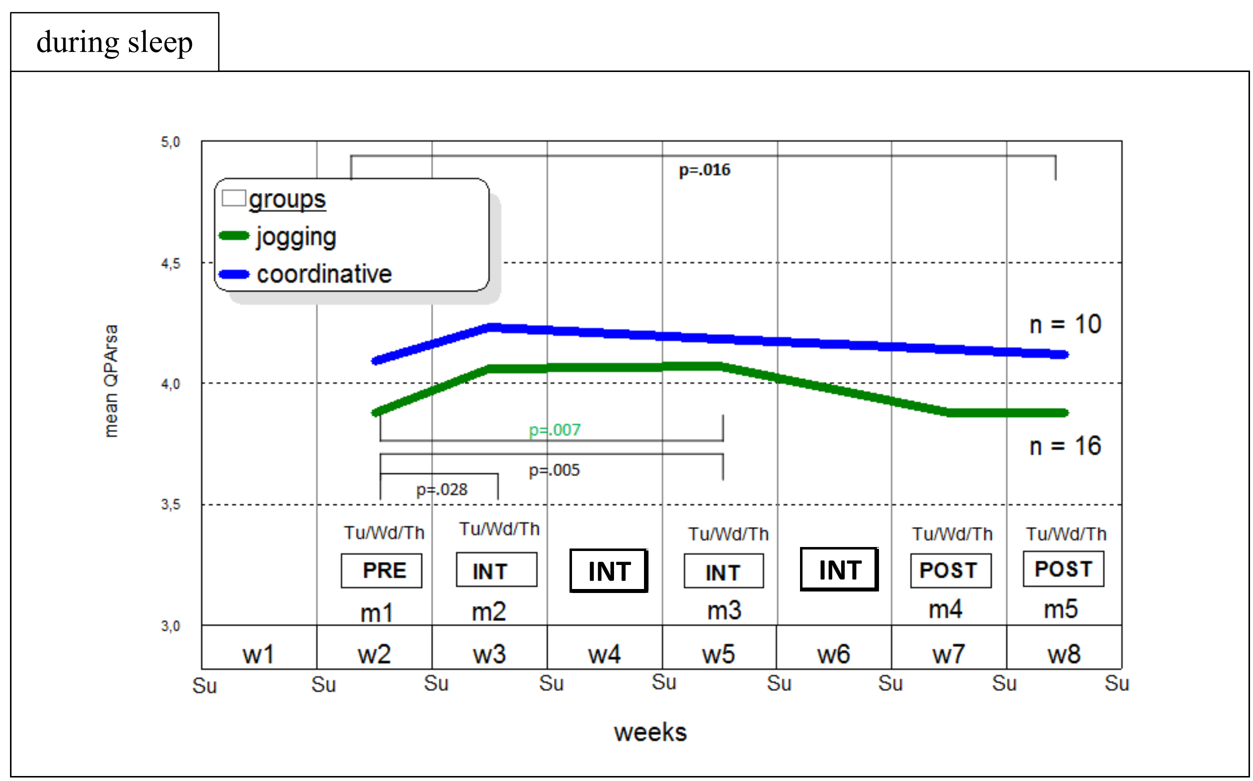


Figure 17: Development of the Pulse-Respiratory Quotient (PRQ) in a sample of N= 26 during sleep Significant p- values of overall (in black) and univariate paired t-test comparisons (in colour)

Figure 17 shows the development of the Pulse-Respiratory Quotient with its significant main effect (p=.016). Between m1 and m2, the PRQ increased in both groups (significant in overall analysis), but then showed a different development: the PRQ of the coordinative group declined after m2 and approximately reached the basal level at the end of the study. Although there was a steady increase of the PRQ in the jogging group until m3, a decrease could be observed until the end.

Total variability (TOTrr)

The total variability (TOTrr) represents the total frequency domain. Descriptive values with their overall analysis are represented in

Table 16, indicating a significant main effect (p=.028). Univariate analysis tended to show a significance (p=.095) in the coordinative group.

Table 16: Descriptive values of total variability (TOTrr) in a sample of N= 26 during sleep (p: time=.028, time*group=.212, group=.136)

		m1	m2	m3	m4	m5
Jogging (N= 16)	mean	8,37	8,29	8,39	8,42	8,27
	SD	0,51	0,68	0,63	0,56	0,41
Coordinative (N=10)	mean	8,34	8,07	7,97	8,15	7,72
	SD	0,77	0,52	0,31	0,75	0,31

m1-m5: measurement 1- measurement 5; SD: standard deviation

Overall paired t-test comparisons revealed a significant decrease between m1 and m5 (p=.013) and between m4 and m5 (p=.027). Univariate paired t-test comparisons tended to show a significant decrease between m1 and m5 (p=.060) and between m1 and m2 (p=.080) in the coordinative group.

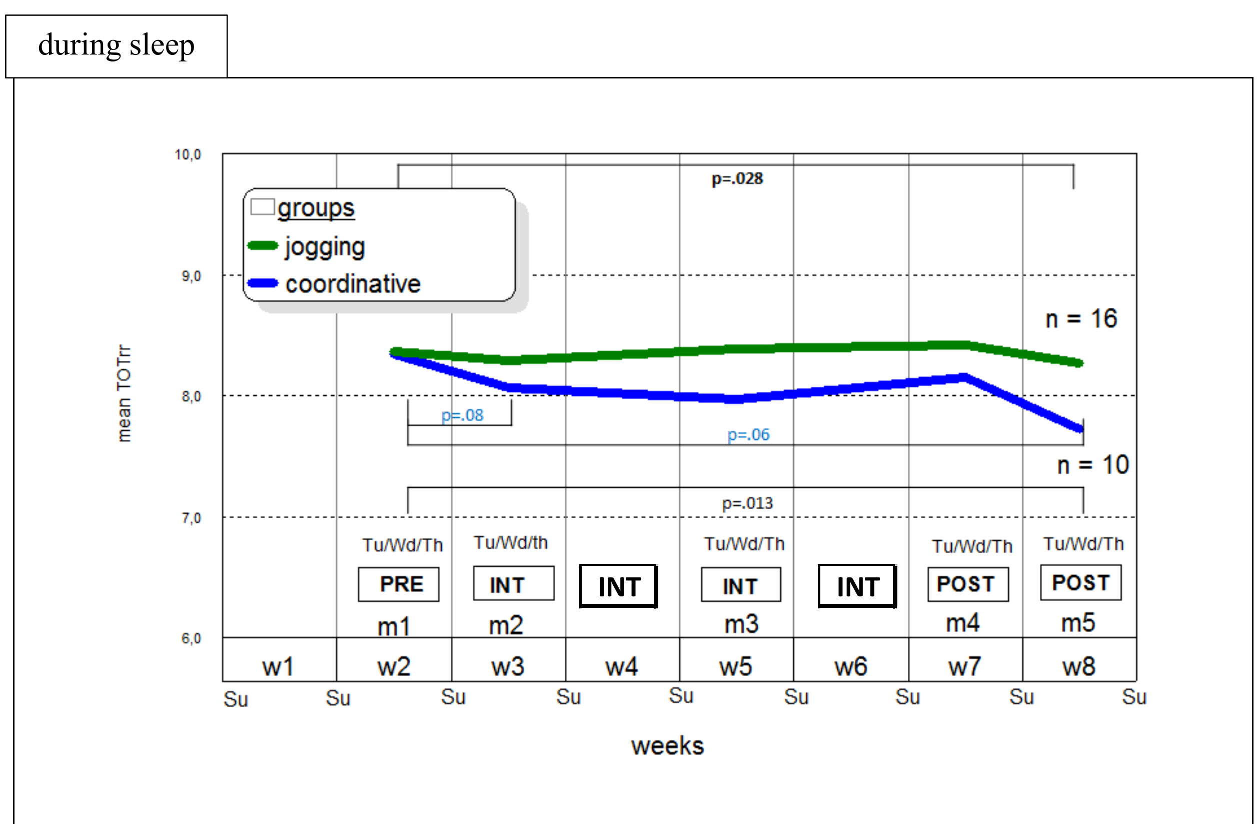


Figure 18: Development of the total variability (TOTrr) in a sample of N= 26 during sleep
Significant p-values of overall (in black) and univariate paired t-test comparisons (in colour)

Figure 18 points out that the coordinative group diminished the TOTrr until m3; this development led to multiple markers of quiet sleep and agreed with the results of VQrr. The jogging group raised the TOTrr during the intervention until m4, demonstrating a higher activity potential and unquiet sleep.

3.1.2 Autonomic sleep quality

3.1.2.1 Different impacts of both training interventions on autonomic sleep quality

Vegetative Quotient (VQ)

The ratio between low frequency variability (LF) and high frequency variability (HF) forms the VQ, determining the balance of the autonomic nervous system. High values show an active, high-performance phase of the body and low values represent relaxation. Descriptive results with their overall analysis are represented in Table 17, illustrating a significant interaction effect (p=.020). Univariate analysis revealed a significant main effect in the jogging group (p=.023).

Table 17: Descriptive values of the Vegetative Quotient (VQ) in a sample of N= 26 during sleep
(p: time=.740, time*group=.020, group=.843)

		m1	m2	m3	m4	m5
Jogging (N= 16)	mean	-0,2	-0.05	-0,16	-0,24	-0,3
	SD	0,57	0,55	0,41	0,55	0,5
Coordinative (N=10)	mean	-0,15	-0,2	-0,18	-0,13	-0,1
	SD	0,41	0,46	0,41	0,56	0,5

m1-m5: measurement 1- measurement 5; SD: standard deviation

Overall paired t-test comparisons did not demonstrate any importance. Univariate paired t-test comparisons revealed a significant increase between m1 and m2 (p=.006) as well as a significant decrease between m3 and m5 (p=.044) and between m2 and m5 (p=.003) in the jogging group. The comparisons also showed a significant increase between m2 and m5 (p=0.039) in the coordinative group.

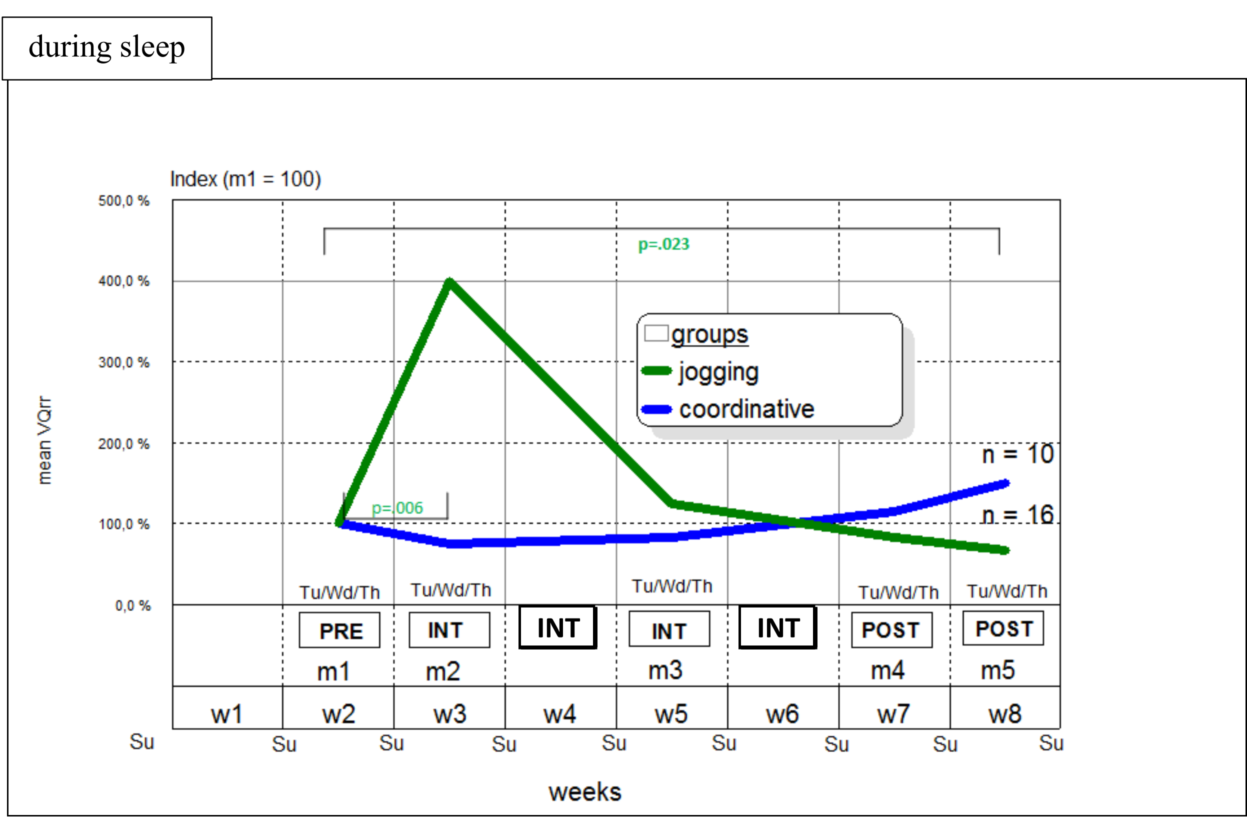


Figure 19: Development of the Vegetative Quotient (VQ) in a sample of N= 26 during sleep
Univariate p-values in green

Figure 19 shows the different impact of the two types of sport intervention on autonomic balance, indicating that the beginning of the intervention led to physiological adaptive processes, as seen in the VQ. To better compare the interaction, this figure is illustrated as index with 100% at m1.

The low value of the Vegetative Quotient in the coordinative group continued during the intervention period and caused a better autonomic sleep recovery. The jogging group reached a high level of activation during sleep, which was responsible for a lower nocturne recovery. After the intervention period, only the jogging group achieved vegetative polarisation.

LowFrequency (LFhf)

The LowFrequency (LFhf) is influenced by the parasympathetic and sympathetic system and corresponds to the blood pressure rhythm. Descriptive values with its multivariate analysis are represented in Table 18, indicating a significant interaction effect (p=.028).

Table 18: Descriptive values of the LowFrequency (LFhf) in a sample of N= 26 during sleep (p: time=.864, time*group=.028, group=.930)

		m1	m2	m3	m4	m5
Jogging (N= 16)	mean	1,46	1,62	1,59	1,57	1,44
	SD	0,4	0,49	0,49	0,4	0,57
Coordinative (N=10)	mean	1,68	1,42	1,45	1,5	1,54
	SD	0,73	0,51	0,48	0,63	0,51

m1-m5: measurement 1- measurement 5; SD: standard deviation

Overall paired t-test comparisons did not demonstrate any significance. Univariate paired t-test comparisons showed a substantial decrease from m2 to m5 (p=.033) in the jogging group and from m1 to m2 (p=.028) in the coordinative group.

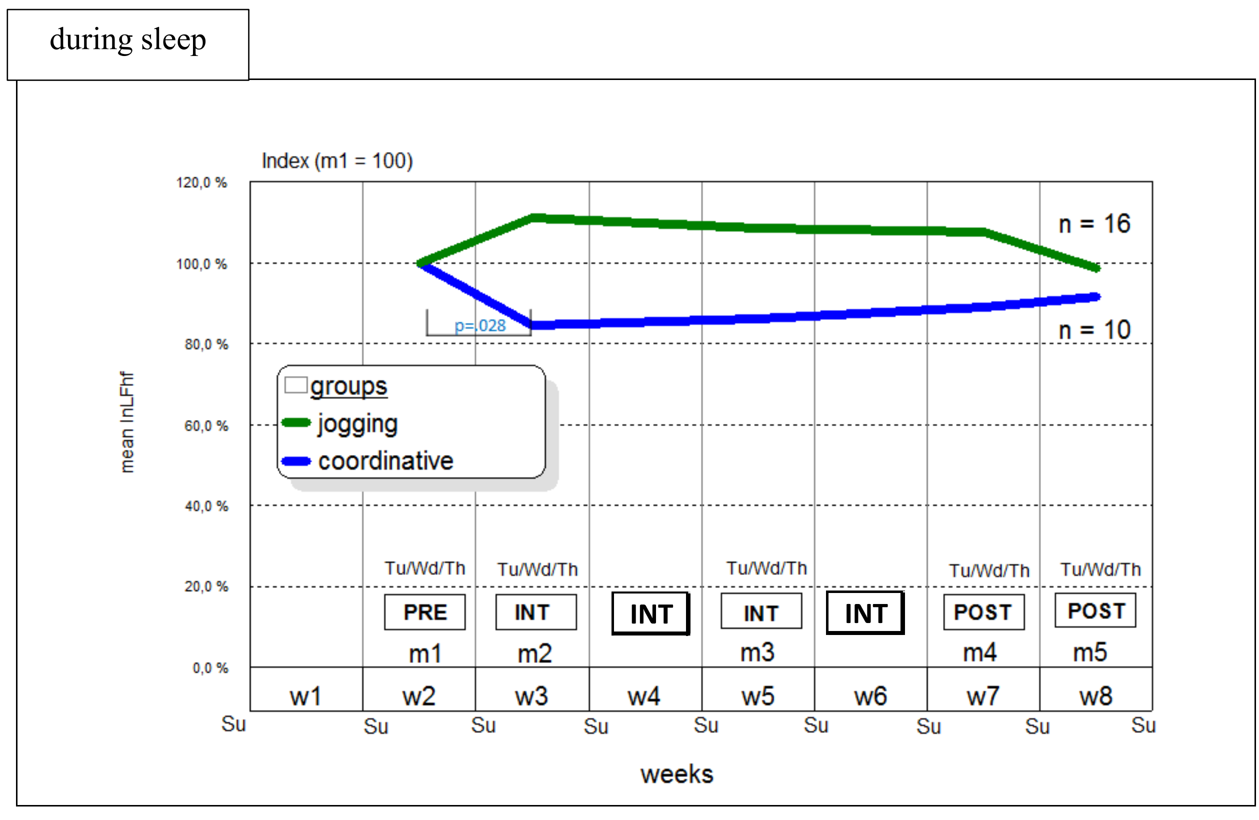


Figure 20: Index of LFhf during sleep in a sample of N=26
One significant p-value of univariate paired t- test comparison in colour

Figure 20 points out the reaction of the sympathetic-vagal modulation during sleep after the training has started and shows the divergent development of both groups.

The jogging group reached the highest value during m2, indicating restless sleep, whereas the coordinative group simultaneously achieved the lowest value. The low frequency of the jogging group began to decrease from m2 to m5 (without significance) and the low frequency of the coordinative group poorly increased from m2 to m5.

3.1.2.2 Development of the autonomic sleep quality by SQidx

Sleep quality index (SQidx)

SQidx, the ratio between heart rate (HR) and vegetative quotient (VQ), gives information about the autonomic regulation of sleep. Descriptive values with their overall analysis are represented in Table 19, indicating a significant group effect (p=.016) and a nearly significant interaction (p=.080).

Table 19: Descriptive values of the sleep quality index (SQidx) in a sample of N= 26
(p: time=.867, time*group= .080, group= .016)

		m1	m2	m3	m4	m5
Jogging (N= 16)	mean	62,73	56,53	60,11	57,39	64,93
	SD	14,12	20,91	15,26	15,64	12,8
Coordinative (N=10)	mean	69,86	72,54	71,31	75,88	69,98
	SD	8,71	8,99	7,6	9,36	11,18

m1-m5: measurement 1- measurement 5; SD: standard deviation

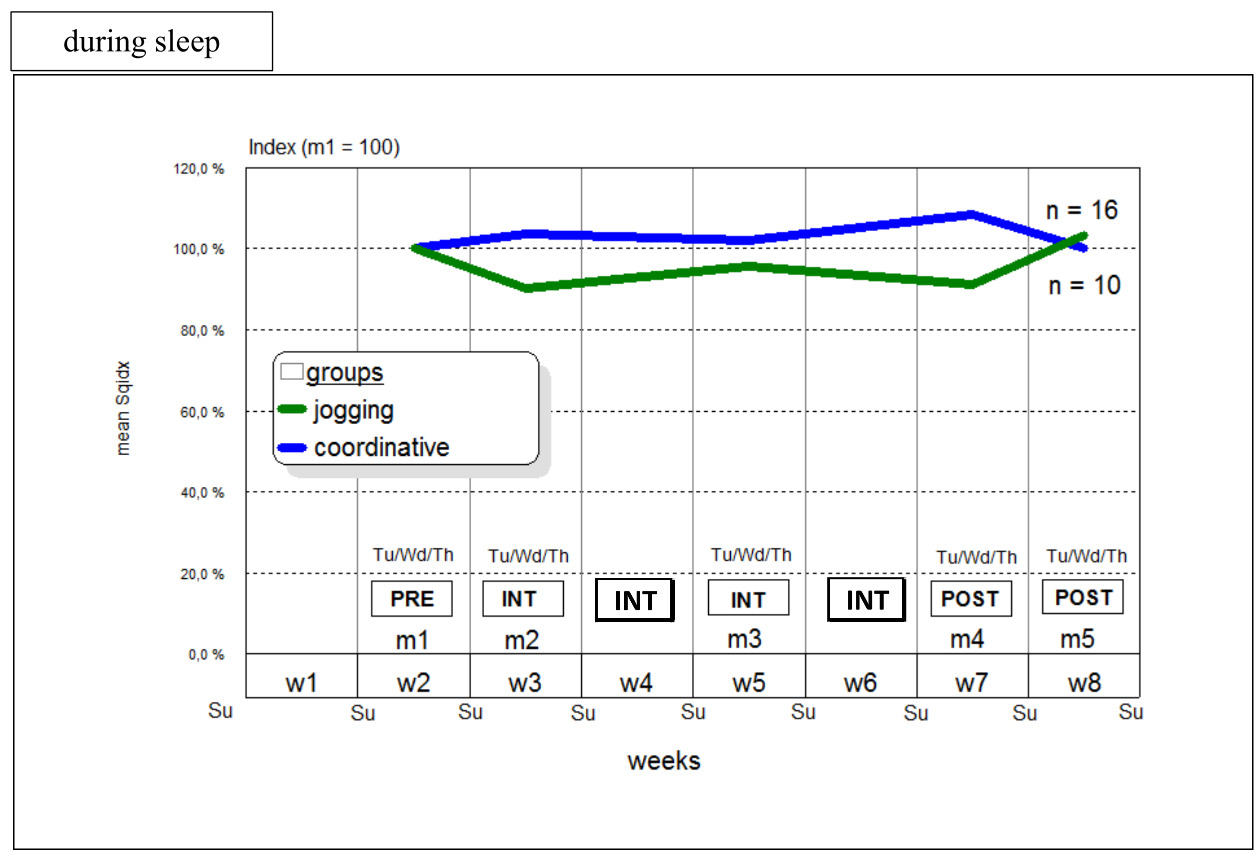


Figure 21: Development of the Sleep Quality Index (SQidx) in a sample of N= 26

Figure 21 shows the different development of the SQidx: at the beginning of the training, it can be observed that both interventions had an impact on autonomic modulation during night, but significantly differed in their influence on the autonomic sleep quality. The group using coordinative exercises had better sleep structure from the beginning to the end (group effect: p=.016). An *M*-like development in the coordinative and a *W*-like development in the jogging group could be observed, indicating that the SQidx always contrastingly increased or declined compared to the other group.

3.1.2.3 Development of the sleep quality by sleeping questionnaires

HRI

Aktuelle Schlaferholung

Descriptive values of “Akuelle Schlaferholung,” with their overall analysis, are represented in Table 20, indicating a significant main effect (p=.001). Univariate analysis revealed a significant main effect in the jogging (p=.015) and coordinative group (p=.001).

Table 20: Descriptive values of “Aktuelle Schlaferholung" in a sample of N= 26
(p: time .001, time*group= .121, group= .661)

		m1	m2	m3	m4	m5	m6	m7	m8
Jogging (N= 16)	mean	17,06	15,91	15,29	17,46	17,21	18,63	18,2	17,31
	SD	3,08	4,03	5,13	4,0	3,75	4,13	3,3	3,79
Coordinative (N=10)	mean	15,9	16,7	18,11	17,2	16,35	20,01	18,5	18,5
	SD	4,34	3,24	3,59	2,9	3,84	4,04	2,29	2,8

m1-m8: measurement 1- measurement 8; SD: standard deviation

Figure 22 shows the development of both groups during 8 weeks with a significant main effect (p=.001). Overall paired t-test comparisons of “Aktuelle Schlaferholung” revealed a significant increase between m2 and m7/m8, between m1 and m7/m8 as well as between m1/m2/m3/m4/m5 and m6 (p<.05). Significant mean differences between pre- to intervention period and pre- to post-intervention period are additionally marked in black in the figure below.

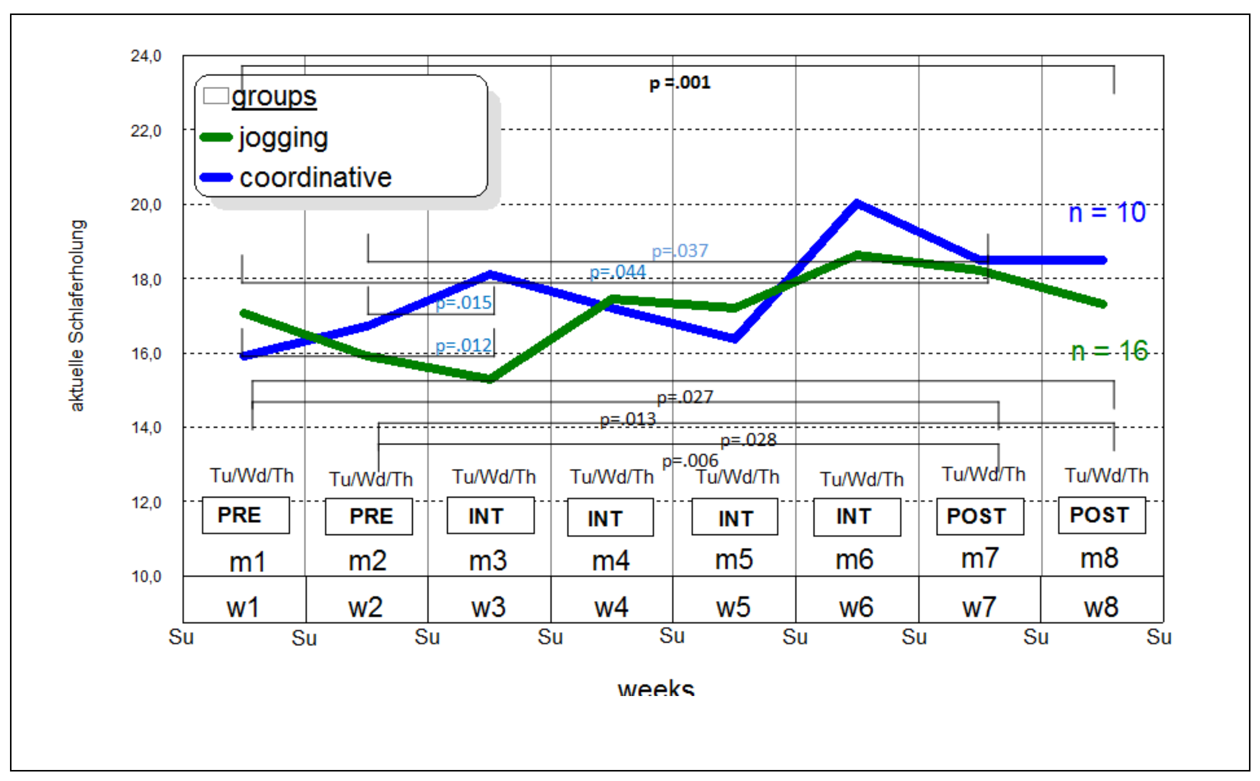


Figure 22: "Aktuelle Schlaferholung" in both groups over 8 weeks in a total sample of N= 26 Significant p-values of overall (in black) and univariate paired t-test comparisons (in colour)

Univariate paired t-test comparisons showed a significant increase between m3 and m4/m6/m7/m8 in the jogging group and again a significant increase between m1 and m3/m6/m7, between m2 and m3/m6/m7 as well as between m4/m5 and m6 ($p<.05$) in the coordinative group

Schlafbewertung

Descriptive values of “Schlafbewertung” with their overall analysis are represented in Table 21, indicating a significant main effect (p=.001). Univariate analysis revealed a significant main effect in the jogging (p=.045) and in the coordinative group (p=.035).

Table 21: Descriptive values of “Schlafbewertung” in a sample of N=26
(p: time=.001, time*group=.682, group= .762)

		m1	m2	m3	m4	m5	m6	m7	m8
Jogging (N= 16)	mean	1,75	1,88	1,91	2,22	2,12	2,41	2,18	2,12
	SD	0,71	0,97	1,04	0,97	0,79	0,97	0,95	0,92
Coordinative (N=10)	mean	1,85	1,75	1,75	1,9	1,75	2,42	2,15	2,3
	SD	0,85	0,76	0,98	0,77	0,89	1,1	0,91	0,75

m1-m8: measurement 1- measurement 8; SD: standard deviation

Figure 23 shows the development of “Schlafbewertung” during 8 weeks with a significant main effect (p=.001). Overall paired t-test comparisons of “Schlafbewertung” revealed a significant increase between m2 and m7/m8, between m1 and m7/m8 as well as between m3 and m8. The paired t-test comparisons also showed a significant increase between m1/m2/m3/m4/m5 and m6, ($p<0.05$).

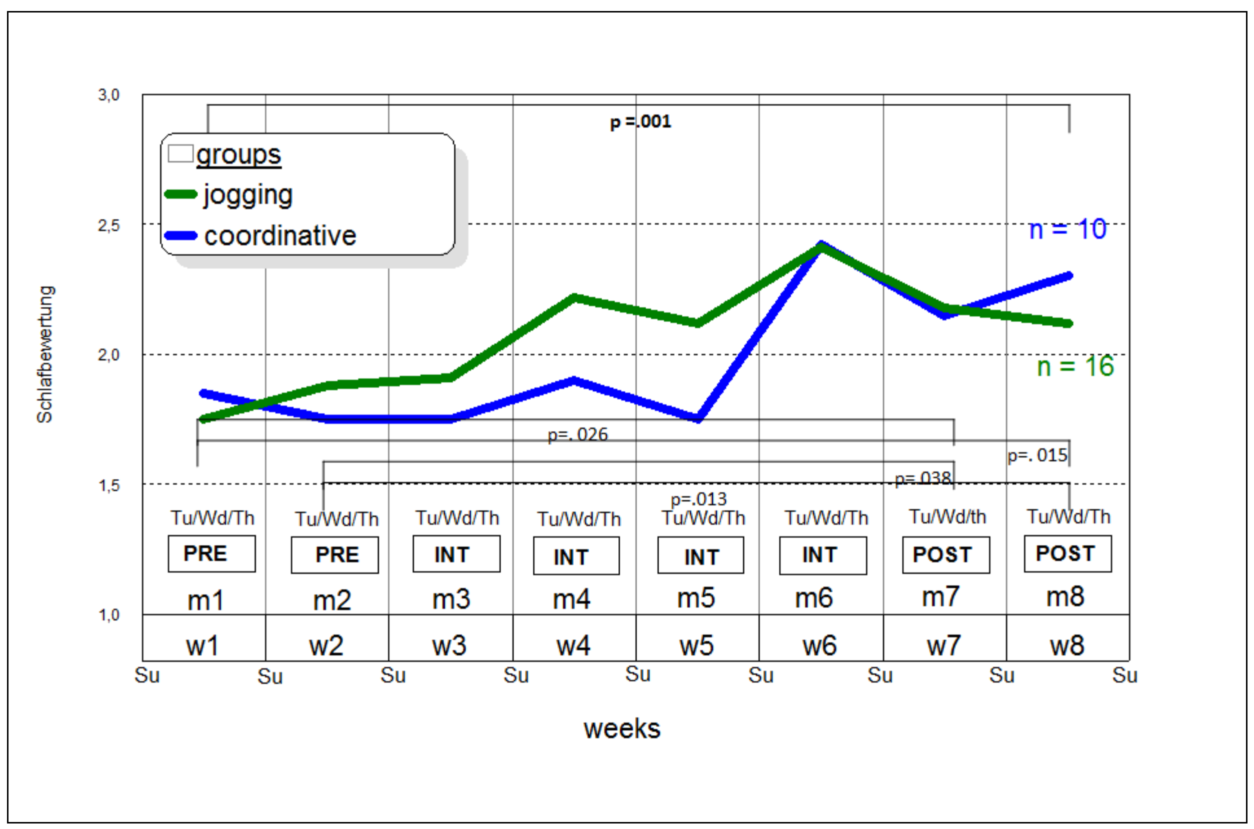


Figure 23: “Aktuelle Schlafbewertung” in both groups over 8 weeks in a total sample of N= 26; Significant p-values of overall paired t-test comparisons in black

Univariate paired t-test comparisons showed a significant increase between m1/m2/m3 to m6 in the jogging group and between m1/m2/m3/m5 to m6 in the coordinative group.

Schlaflänge

Descriptive values of “Schlaflänge” with their analysis are represented in Table 22, nearly indicating a significant main effect (p=.069). However, univariate analysis demonstated no significance.

Table 22: Descriptive values of “Schlaflänge” in a sample of N= 26
(p: time=.069, time*group= .170, group= .096)

		m1	m2	m3	m4	m5	m6	m7	m8
Jogging (N= 16)	mean	2,38	2,09	1,98	2,18	2,17	2,25	2,36	2,14
	SD	0,59	0,69	0,73	0,68	0,73	0,68	0,73	0,51
Coordinative (N=10)	mean	2,15	2,19	0,79	2,6	2,4	2,99	2,75	2,5
	SD	1,06	0,68	3,59	0,52	0,81	0,86	0,68	0,58

m1-m8: measurement 1- measurement 8; SD: standard deviation

Overall paired t-test comparisons of “Schlaflänge” revealed a significant increase between m2/m3 and m6 and between m2 and m7 (p<0.05). Figure 24 shows the development of “Schlaflänge” in both groups during 8 weeks.

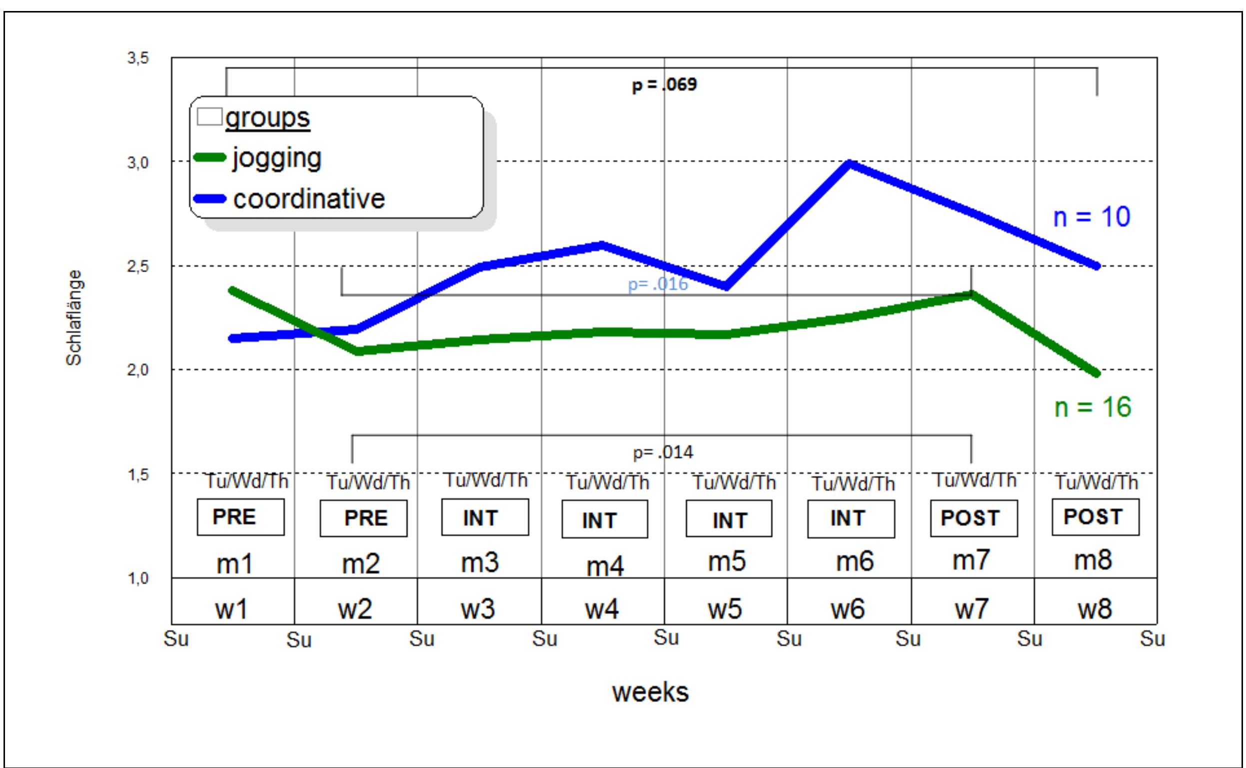


Figure 24: “Schlaflänge” in both groups over 8 weeks in a total sample of N= 26
Significant p-values of overall (in black) and univariate paired t- test comparisons (in colour)

Univariate paired t- test comparisons showed a significant increase between m2 and m7 in the coordinative group (p=.016).

3.1.3 ON effect of the training during the interims between pre- to intervention period

During sleep

Respiratory sinus arrhythmia (RSArr)

The respiratory sinus arrhythmia (RSA), a marker of vagal activity, is the highly-frequent variability of heart rate that reflects the modulation of the heartbeat through the respiratory system. Descriptive values with its overall analysis are represented in Table 10, indicating no significant effects. The interim between m1 to m2 (pre- to intervention period) was of further interest.

Table 23: Descriptive values of respiratory sinus arrhythmia (RSA) in a sample of N= 26 during sleep (p: time=.152, time*group= .645, group= .243)

		m1	m2	m3	m4	m5
Jogging (N= 16)	mean	1,62	1,56	1,6	1,63	1,65
	SD	0,15	0,19	0,17	0,18	0,21
Coordinative (N=10)	mean	1,58	1,51	1,51	1,52	1,53
	SD	0,18	0,15	0,24	0,25	0,21

m1-m5: measurement 1- measurement 5; SD: standard deviation

Figure 25 shows the development of the RSArr during sleep, with the main focus on the interim between m1 to m2. The bodily system immediately responded to the sportive stimulus with a decrease of vagal modulation seen in the RSArr with its minimum value during m2 in both groups.

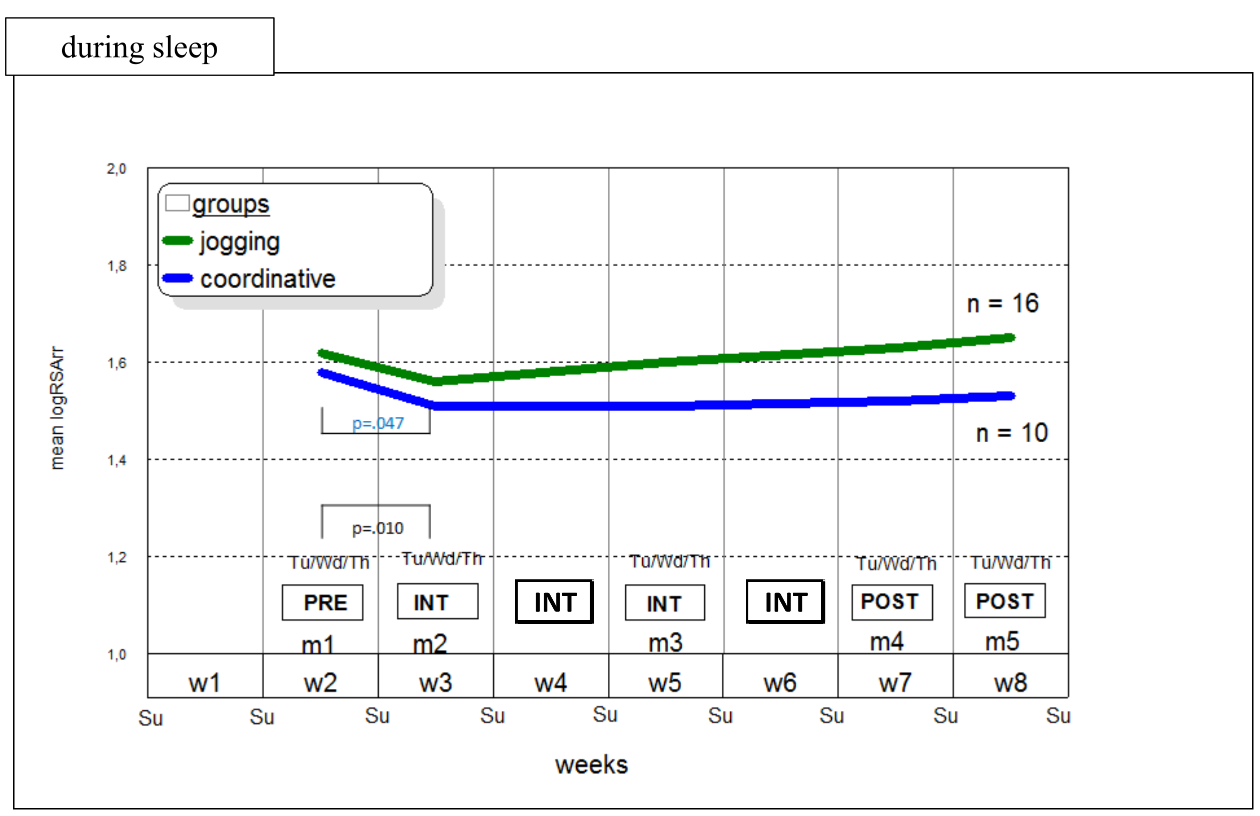


Figure 25: Development of the respiratory sinus arrhythmia (RSA) in a sample of N= 26 during sleep Significant p-values of overall (in black) and univariate paired t- test comparison (in colour)

Overall paired t-test comparisons revealed a significant decrease (p=.010) between m1 and m2. Univariate paired t- test comparisons showed a significant increase between m2 and m5 in the jogging group (p=.038) and a significant decrease between m1 and m2 in the coordinative group (p=.047).

The main findings of PRQ, LFhf and HR during sleep have been documented on the preceding pages. The PRQ (p=.028) and the HR (p= .004) revealed a significant ON-effect between pre- to intervention period. LFhf showed a highly-significant interaction effect (p= .004) during this interim.

During circadian variations

A circadian variation is determined by the difference between day and sleep, meaning fluctuations that occur during the day.

Low Frequency (LFhf)

LFhf continued to show a significant interaction effect (p=.007). Descriptive values with their overall analysis are represented in Table 24. Univariate analysis almost revealed a main effect in the jogging group (p=.084).

Table 24: Circadian variations of Low Frequency (LFhf) in a sample of N= 26
(p: time= .733, time*group= .007, group= .688)

		m1	m2	m3	m4	m5
Jogging (N= 16)	mean	1,41	1,21	1,19	1,25	1,36
	SD	0,47	0,54	0,57	0,46	0,49
Coordinative (N=10)	mean	1,17	1,51	1,36	1,39	1,36
	SD	0,66	0,47	0,4	0,53	0,43

m1-m5: measurement 1- measurement 5; SD: standard deviation

Figure 26 shows a comparison of LFhf during day and sleep, shown in green for the jogging group and blue for the coordinative group. The groups differed in their development, especially after the first week of intervention: during sleep, the LF values declined in the coordinative group and rose in the jogging group from pre- to intervention period; during the day, the values of the jogging group did not change fundamentally, but they augmented in the coordinative group. This increase led to a better circadian variation, indicating a vitalisation, which means that the dipping structure contributed to a higher vitalisation in the coordinative group than in the jogging group, which failed to show a changed structure of LF during the day.

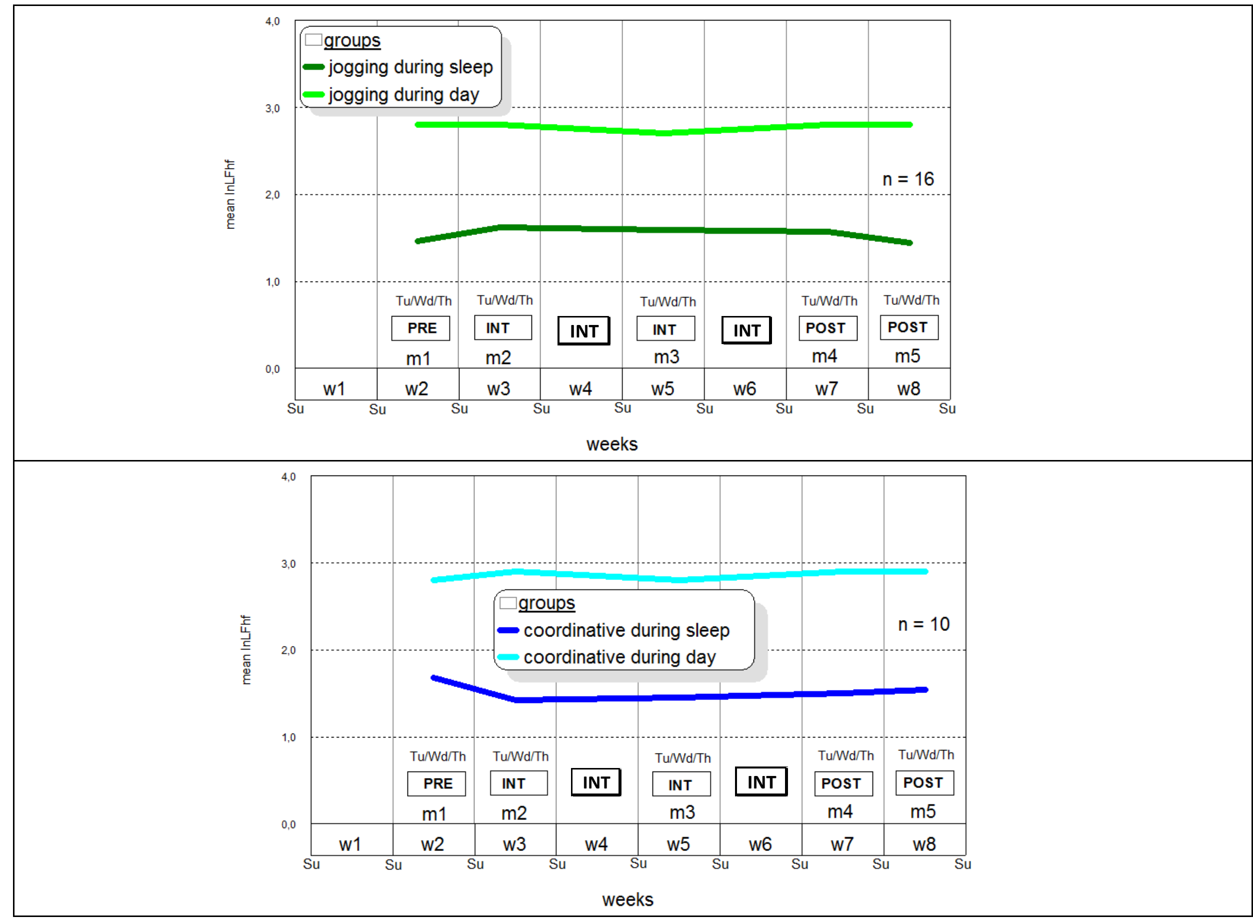


Figure 26: Development of the Low Frequency (LFhf) during sleep and day in the jogging group (N=16) in green and in the coordinative group (N=10) in blue

This high vitalisation of the coordinative group during the day can be seen in Figure 27as well. The quotient (day/sleep) of the LF- values was calculated and was demonstrated as Index in %.

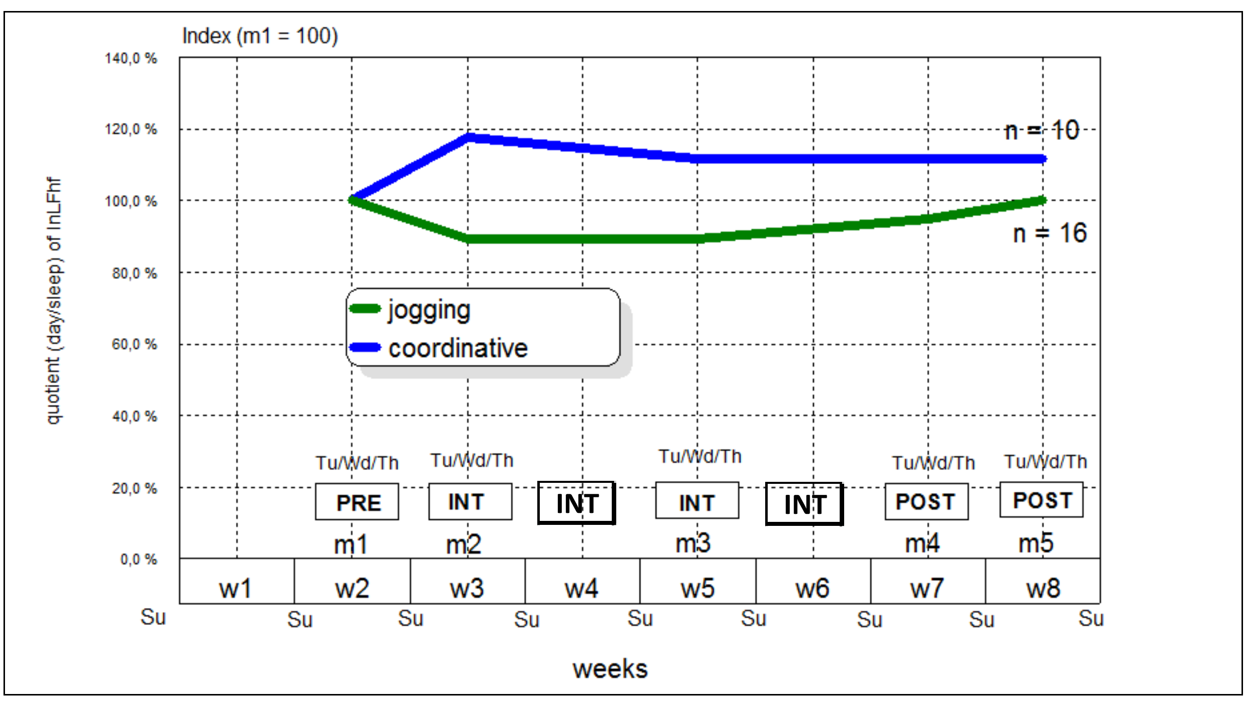


Figure 27: Quotient (day/sleep) of LFhf expressed as Index in the jogging (n=16) and in the coordinative Group (N= 10)

Figure 28 shows the divergent development of both groups with a significant interaction (p=.007) during circadian variations. Overall paired t-test comparisons did not demonstrate a significance but univariate comparisons revealed a significant decrease from m1 to m4 (p=.004) in the jogging group and a significant increase from m1 to m2 (p=.002) and m1 to m4 (p=.024) in the coordinative group.

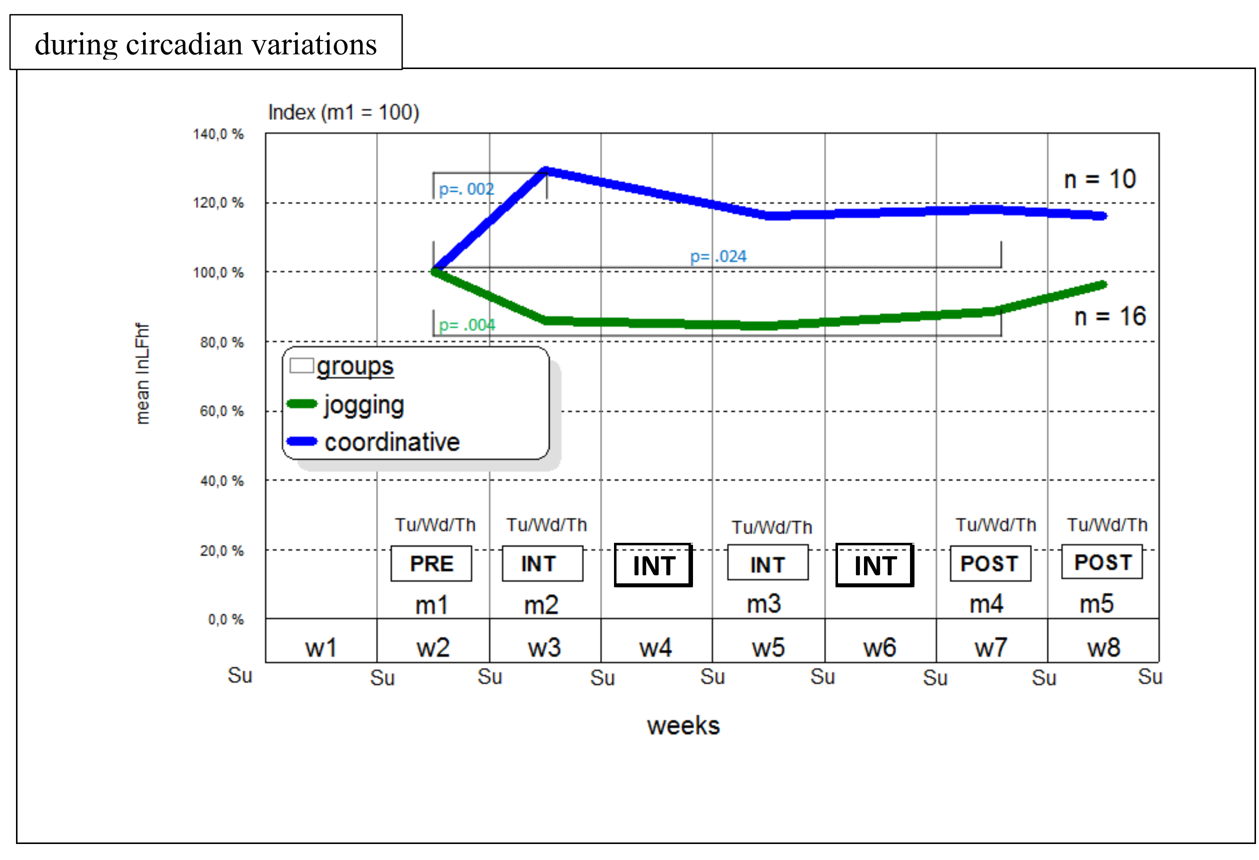


Figure 28: Cirdcadian variations of Low Frequency (LFhf) in a sample of N= 26
Significant p-values of univariate paired t- test comparison in colour

Figure 28 demonstrates that the coordinative group was able to increase the LFhf values during circadian variations, whereas the jogging group reached the lowest level of LFhf after the first week of training.

High Frequency (HFhf)

Overall analysis of HFhf during circadian variations nearly revealed an interaction effect (p=.068).

Figure 29 shows a comparison of HFhf during the day and sleep, in green for the jogging and in blue for the coordinative group. In the jogging group, the vagal modulation decreased during both sleep and day after one week of training, whereas the development of HF values in the coordinative group differed between sleep and day. During the day between the pre- to the intervention period, the coordinative group was able to augment the level of parasympathetic modulation a little bit, but during sleep the vagal capacity decreased.

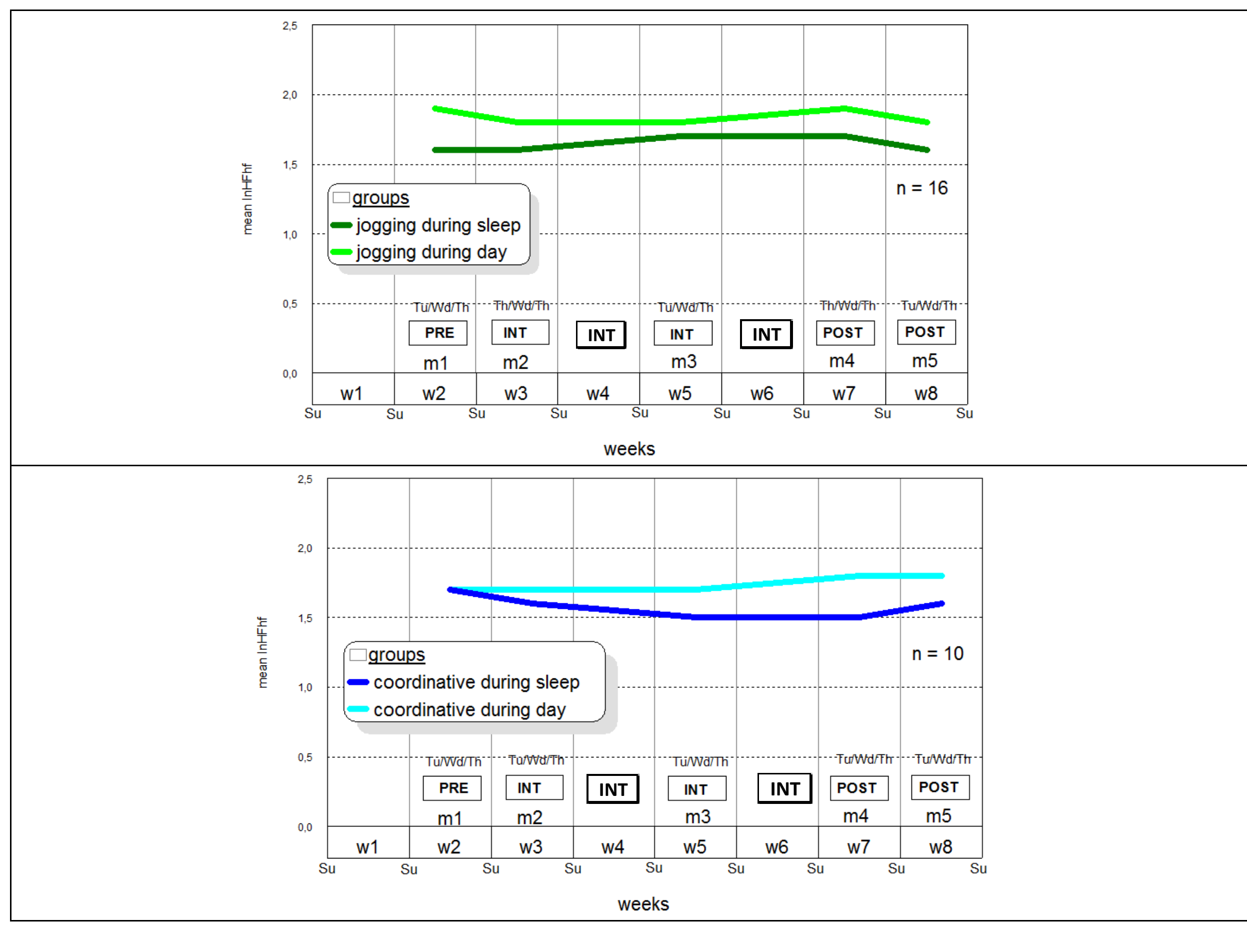


Figure 29: Development of the High Frequency (HFhf) during sleep and day in the jogging group (N= 16) and the coordinative group (N=10)

This development can be also seen in Figure 30, demonstrating the quotient (day/sleep) of HFhf for both groups expressed as Index (%). Coordinative values augmented until the post period. .

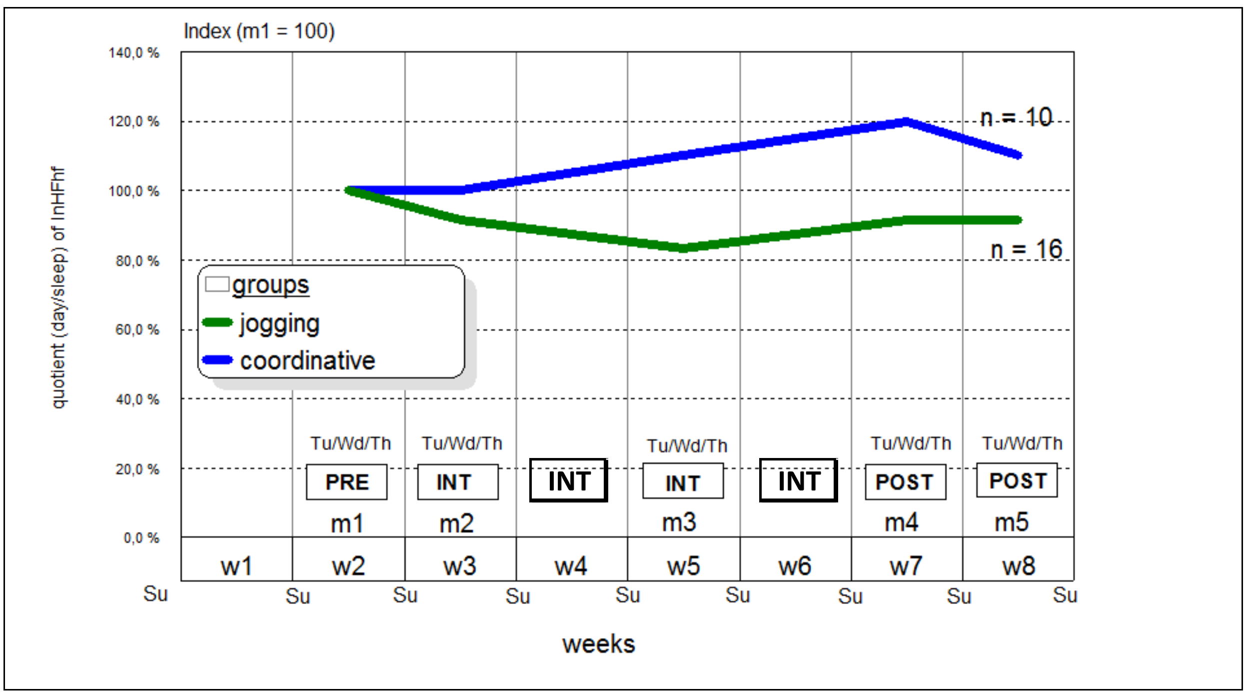


Figure 30: Quotient (day/sleep) of HFhf expressed as Index in the jogging (n=16) and in the coordinative Group (N= 10)

Figure 31 shows the development of HFhf during ciradian variations with a tendency to a significant interaction (p=.068). Again, the interim between pre- to intervention period was of further interest and showed a divergent development. During circadian variations, the coordinative group was able to increase the vagal modulation five times more, whereas the jogging group diminished the parasympathetic outflow.

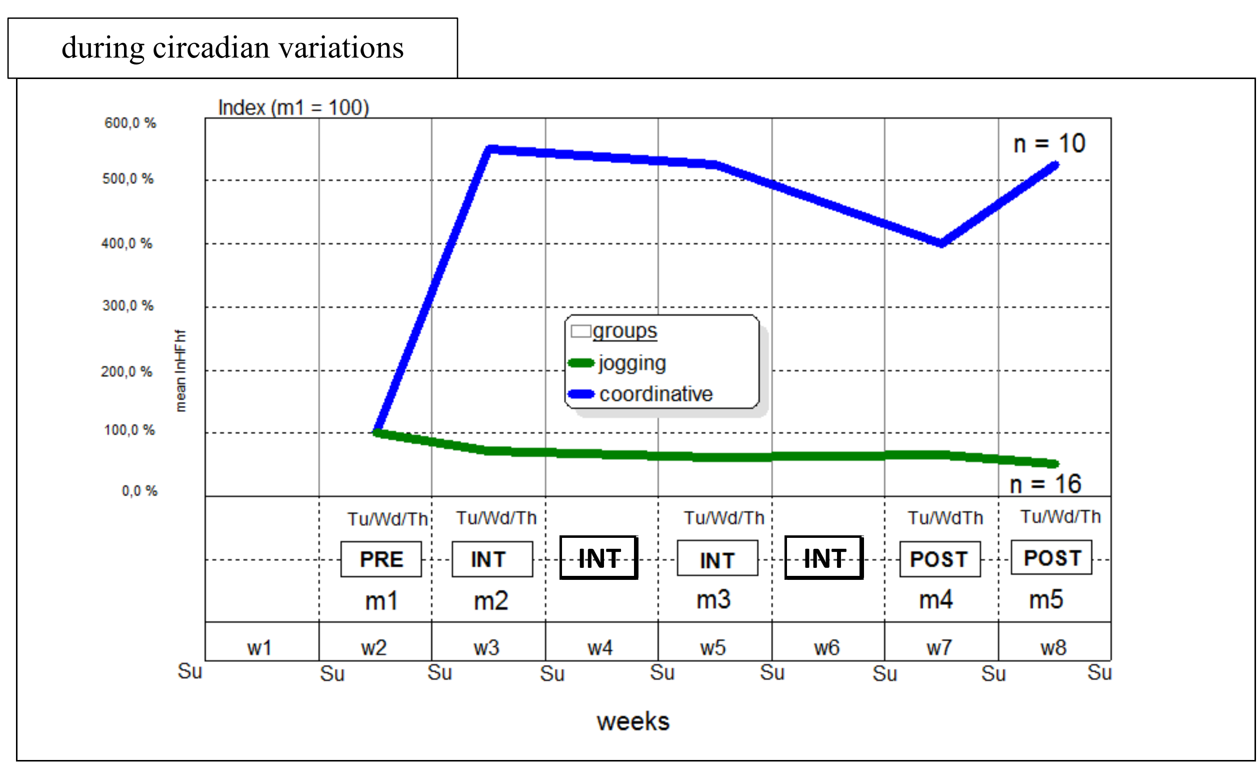


Figure 31: Circadian variations of High Frequency (HFhf) in a sample of N= 26

3.2 Sport scientific parameters

3.2.1 Heart rate (HR)

Figure 32 shows the development of the heart rate during the day and sleep, in green for the jogging group and in blue for the coordinative group. The effectiveness of the jogging intervention led to a significant decrease of the HR during the day (p=.040) and during sleep (p=.045). The jogging group achieved an average value of 90.3 beats per minute during the day and an average value of 64.2 beats per minute during sleep. The coordinative group revealed higher mean values: 94.4 beats per minute during the day and 68.2 beats per minute during sleep without a significant main effect.

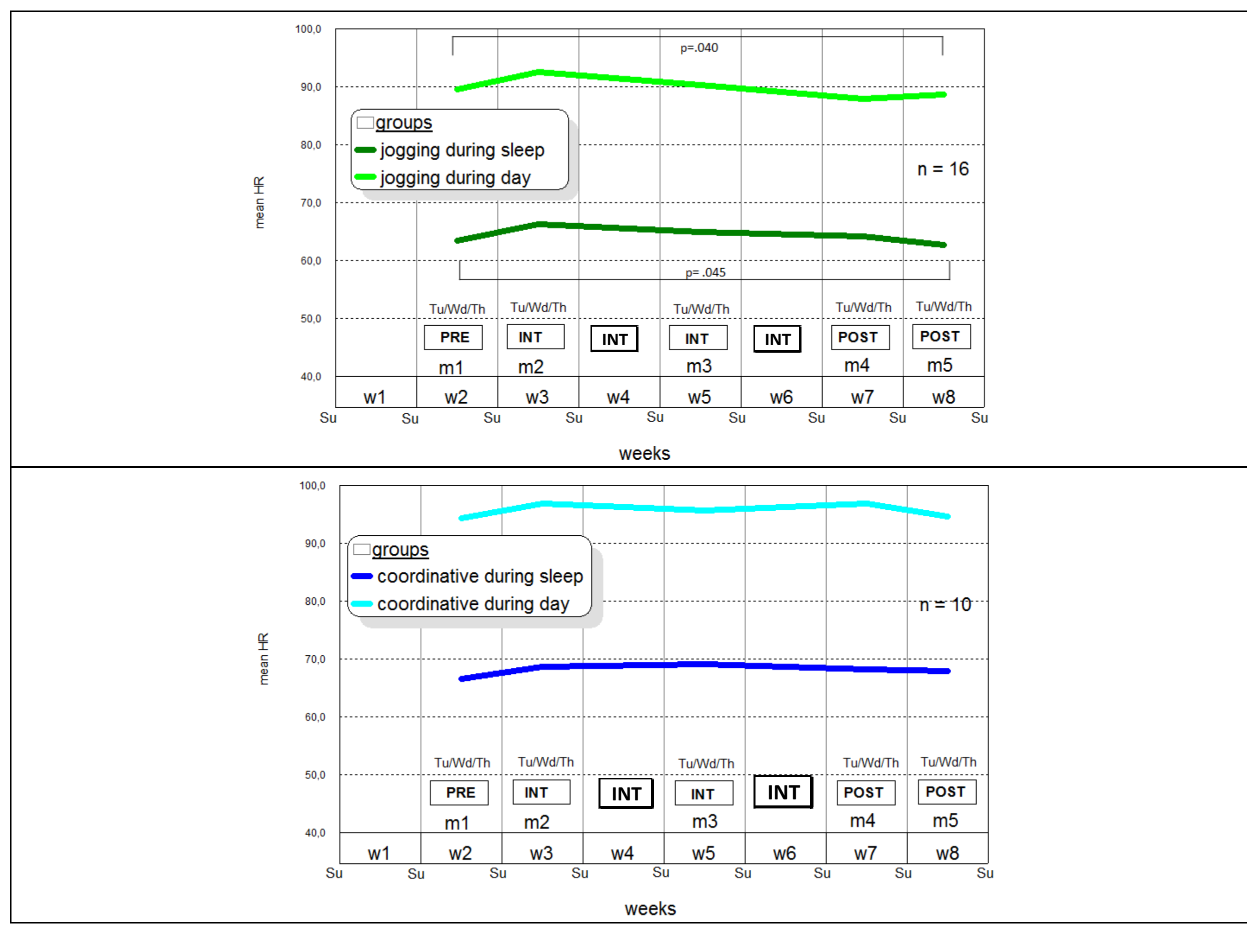


Figure 32: Development of the Heart Rate (HR) during sleep and day in green for the jogging group (N= 16) with a significant main effect during day (p=.040) and during sleep (p=.045), in blue for the coordinative group (N= 10) without significance

3.2.2 Aerobic capacity

Descriptive values of the shuttle run with an operated analysis can be seen in Table 25, indicating a significant time effect (p= .001).

Table 25: Levels of the "shuttle run" in a sample of N= 26 (time (p)= .001/ time* group= .497/ group= .440) on the left side and converted into VO_{2max} values on the right side

Shuttle run		PRE	POST
Jogging (N= 16)	mean	5,44	6
	SD	1,26	1,26
Coordinative (N=10)	mean	4,9	5,7
	SD	1,37	1,77

VO_{2max}		PRE	POST
Jogging (N= 16)	mean	32,84	34,76
	SD	4,56	3,94
Coordinative (N=10)	mean	31,44	33,53
	SD	4,98	5,71

The classification of trained/ average/ untrained girls can be seen in Table 26. Fifteen girls were classified as untrained, 6 girls as average and 5 as trained.

Table 26: Classification of trained/ average/ untrained girls in a sample of N= 26

	trained	average	untrained
Coordinative group (N= 10)	N= 2	N= 0	N= 8
Jogging Group (N= 16)	N= 3	N= 6	N= 7
Total (N= 26)	N= 5	N= 6	N= 15

In Figure 33, the shuttle run level before and after the intervention is shown for both groups. It can be seen that the jogging group achieved a higher level of cardio-respiratory fitness before and after the intervention with a high significant main effect (p=.003). Analysis of the coordinative group also revealed a significant main effect (p=.053).

Figure 34 represents the shuttle run values of all girls split off into the classification trained/ average/ untrained. This diagram demonstrates that each classification group was able to improve the fitness profile after the intervention program with a significant main effect in the untrained (p=.027) and trained girls (p=.016). The average group simply showed a tendency for a significant improvement of cardiorespiratory fitness (p=.076).

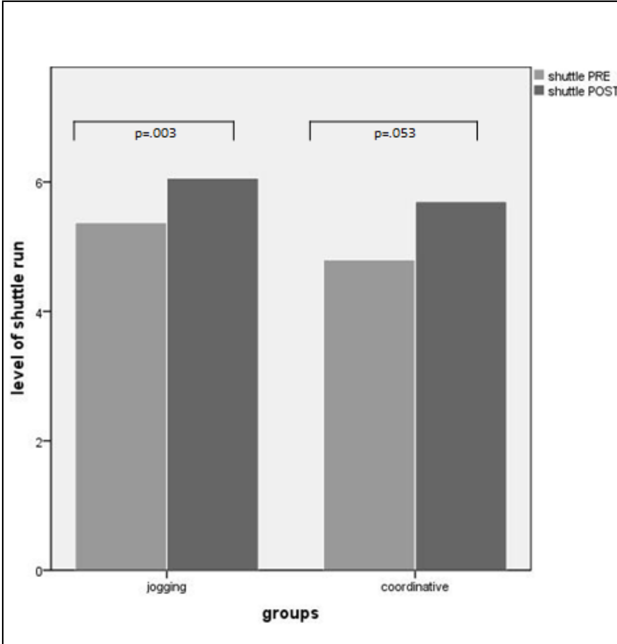


Figure 33: Shuttle run levels before and after the intervention in the jogging group (N= 16) with a main effect (p= 0.003) and in the coordinative (N=10) group with a main effect (p= 0.053)

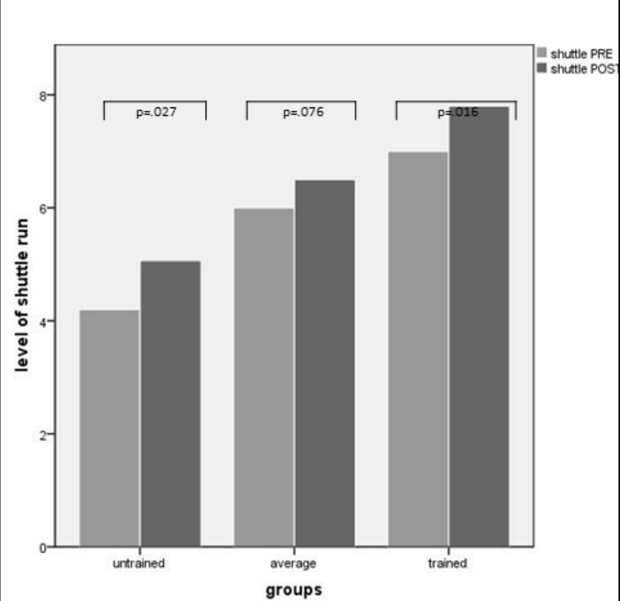


Figure 34: Shuttle run levels split off into untrained (N= 15)/ average (N= 6)/ trained (N= 5) participants before and after the intervention with a significant main effect in the untrained (p= 0.0) and trained (p= 0.027) girls

3.2.3 Questionnaire about Physical Activity (IPAQ)

The results of the IPAQ-short questionnaire show the total amount of physical activity (walking, moderate, vigorous intensity) per week and are expressed in METs[11]. Descriptive values of the IPAQ with their overall analysis are represented in Table 27, indicating a significant main effect ($p>.001$). Univariate analysis also showed main effects in both groups ($p<.001$).

Table 27: The total amount of physical activity in a sample of N= 26 expressed in METs through the IPAQ questionnaire; (p: time=.00, time*group=.223, group=.450)

		m1	m2	m3	m4	m5	m6	m7	m8
Jogging (N= 16)	mean	839,6	908,8	1896,7	1745,3	2554	1487,4	872,6	441,88
	SD	960,5	854,9	1353,7	1134,0	1195,1	736,9	862,1	544,07
Coord. (N=10)	mean	606,4	834,5	2050,6	2558,1	2437	1857,9	1555,8	525,2
	SD	821,4	1030,7	770,3	1137,5	1662,5	993,4	1131,1	623,8

m1-m8: measurement 1- measurement 8; SD: standard deviation

Overall paired t-test comparisons revealed a significant increase between m1 and m3/m4/m5/m6, between m2 and m3/m4/m5/m6, as well as between m3 and m5. Significant decreases between m2 and m8, between m3 and m7/m8, between m4 and m6/m7/m8 as well as between m5 and m6/m7/m8 ($p< 0.05$) were observed. Figure 35 shows the development of the amount of physical activity during 8 weeks with a significant main effect ($p=.001$). Significant p-values from pre- to intervention or pre- to post-intervention periods are additionally added in the figure.

[11] The definition of MET is explained in the introduction

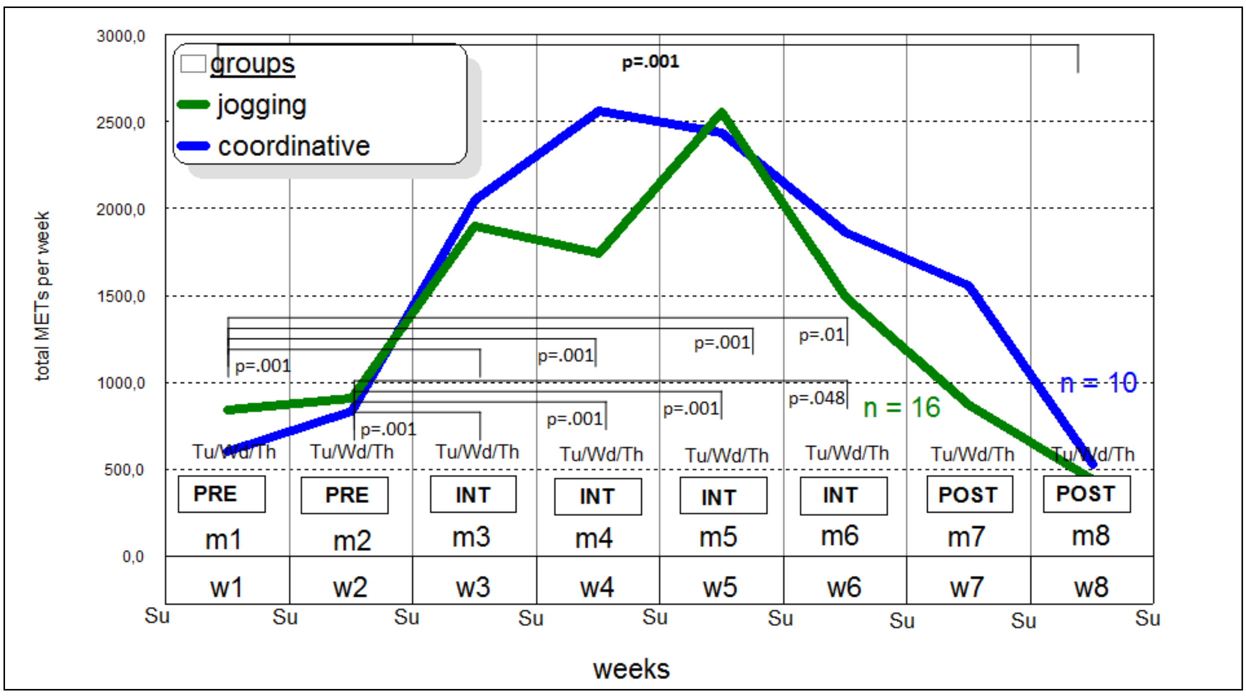


Figure 35: Amount of physical activity during 8 weeks in a sample of N= 26
Overall p-values in black

Univariate paired t-test comparisons revealed a significant increase between m1 and m3/m4/m5, between m2 and m3/m4/m5/m6, between m3 and m5, between m4 and m5, and a significant decrease between m3 and m7/m8, between m4 and m7/m8, between m5 and m6/m7/m8, between m6 and m7/m8, and between m7 and m8 in the jogging group (p<.05). A significant increase appeared between m1 and m3/m4/m5/m6/m7, between m2 and m3/m4/m5/m6 and between m8 and m3/m4/m5/m6/m/ in the coordinative group (p<.05).

3.3 Psychological Parameters

3.3.1 Erholungs-Belastungs-Fragebogen (EBF)

Overall analysis of the EBF questionnaire revealed two significant main effects in "soziale Beanspruchung" ($p=.039$) and "soziale Erholung" ($p=.001$). The subtest "Erholsamer Schlaf" showed a nearly main effect ($p=.060$). Univariate analysis showed a significance of "soziale Beanspruchung" in the jogging group ($p=.039$), and univariate analysis of "soziale Erholung" demonstrated a significant main effect in the coordinative group ($p=.005$)

Overall paired t-test comparisons of "soziale Beanspruchung" revealed a significant increase between w2 and w3 ($p=.018$). They showed a significant decrease between w3 and w7 ($p=.005$) and between w3 and w8 ($p=.001$). Univariate paired t-test comparisons showed a significant decrease between m3 and m2/m7/m8 ($p<.05$) in the jogging group. Figure 36 shows the development of "soziale Beanspruchung" in both groups during 8 weeks.

Overall paired t-test comparisons of "soziale Erholung" revealed a significant increase between w1 and w3/ w4/ w5/ w6/ w7/ w8 and between w2 and w3/ w4/ w5/ w6/ w7/ w8 ($p< .05$). Univariate paired t-test comparisons showed a significant increase between m1 and m3/m4/m5/m6 as well as between m2 and m3. They revealed a significant decrease between m6 and m7 ($p<.05$) in the jogging group. A significant increase between m2 and m4/m5/m6/m7/m8 and between m1 and m7 in the coordinative group could also be observed. Figure 37 shows the development of "soziale Erholung" in both groups during 8 weeks.

Overall paired t-test comparisons of "Erholsamer Schlaf" revealed a significant decrease between w1 and w7 ($p=.033$), between w2 and w4 ($p=.002$), and between w2 and w7 ($p= 0.028$). Univariate paired t-test comparisons expressed a significant decrease between m2 and m4 in the jogging group ($p=.044$) and in the coordinative group ($p=.035$). Figure 38 shows the development of "Erholsamer Schlaf" in both groups during 8 weeks.

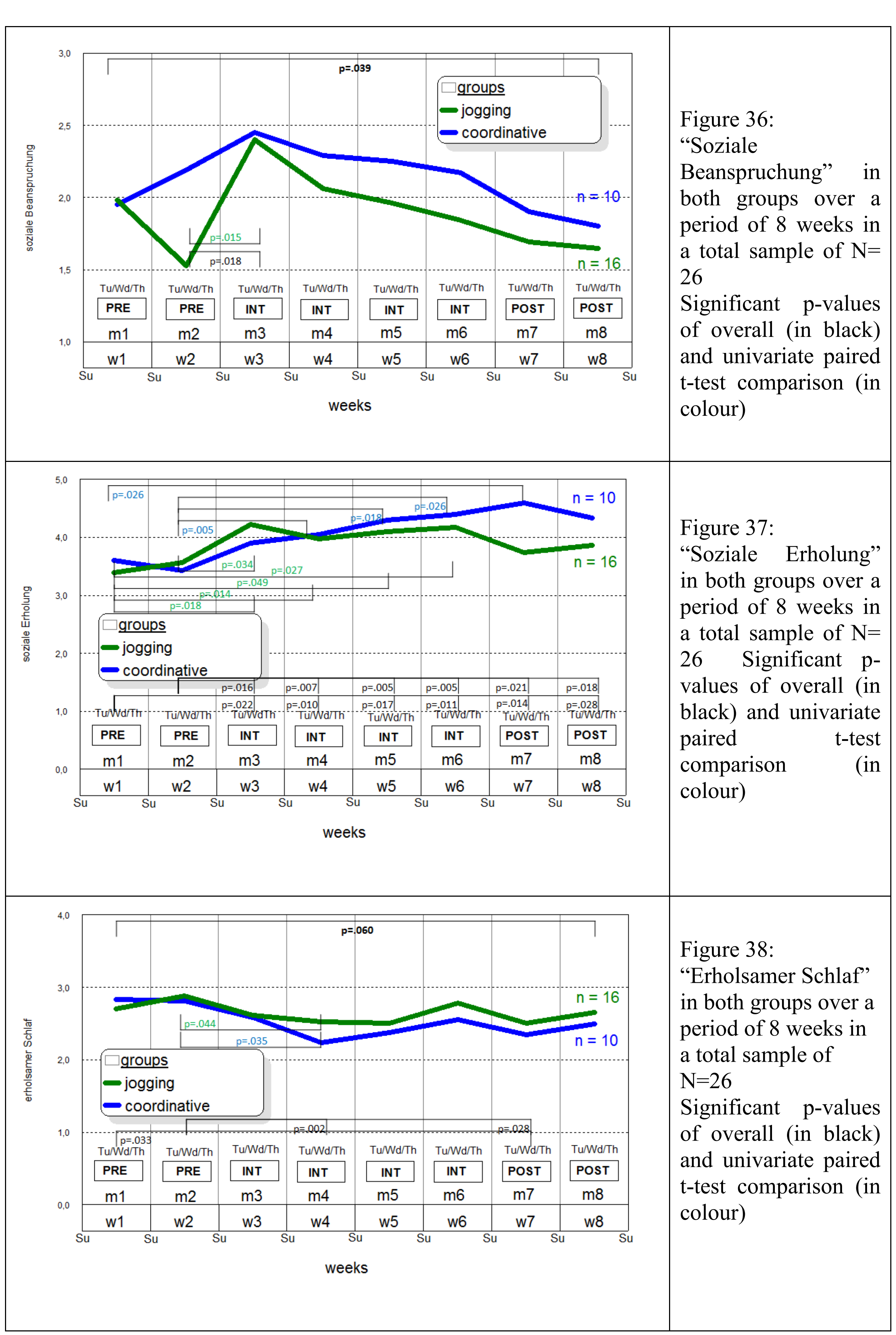


Figure 36: “Soziale Beanspruchung” in both groups over a period of 8 weeks in a total sample of N= 26
Significant p-values of overall (in black) and univariate paired t-test comparison (in colour)

Figure 37: “Soziale Erholung” in both groups over a period of 8 weeks in a total sample of N= 26 Significant p-values of overall (in black) and univariate paired t-test comparison (in colour)

Figure 38: “Erholsamer Schlaf” in both groups over a period of 8 weeks in a total sample of N=26
Significant p-values of overall (in black) and univariate paired t-test comparison (in colour)

3.3.2 Befindlichkeitsskalierung durch Kategorien und Eigenschaftswörter (BSKE)

Overall analysis of the BSKE questionnaire revealed two significant main effects in "Aktiviertheit" ($p=.035$) and "Desaktiviertheit" ($p=.055$). The subtest "Desaktiviertheit" showed a significant interaction effect ($p=.020$). Univariate analyses revealed a significant main effect ($p=.003$) in the jogging group.

Overall paired t-test comparisons of the subtest "Aktiviertheit" revealed a significant decrease between w1 and w4/ w5/ w7, between w3 and w4/ w7 and between w6 and w7 ($p<.05$). Univariate paired t-test comparisons showed a considerable decrease between m3 and m4/m8. They also showed a significant increase between m4 and m6/m1, between m7 and m6/m3/m2/m1 as well as between m8 and m2 in the jogging group ($p<.05$). A significant increase between m5 and m8 was observed in the coordinative group ($p<.05$).

Figure 39 shows the development of "Aktiviertheit" in both groups during 8 weeks.

Overall paired t-test comparisons of the subtest "Desaktiviertheit" revealed a significant decrease between w7 and w1/ w3/ w6/ w8 ($p<.05$). Univariate paired t-test comparisons showed an ample increase between m1 and m2/m3/m4/m5/m7/m8 and a significant decrease between m7 and m3/m6/m8 in the jogging group. A considerable decrease between m1 and m6/m8 and between m3 and m8 in the coordinative group ($p<.05$) was observed.

Figure 40 demonstrates the development of "Desaktiviertheit" in both groups during 8 weeks.

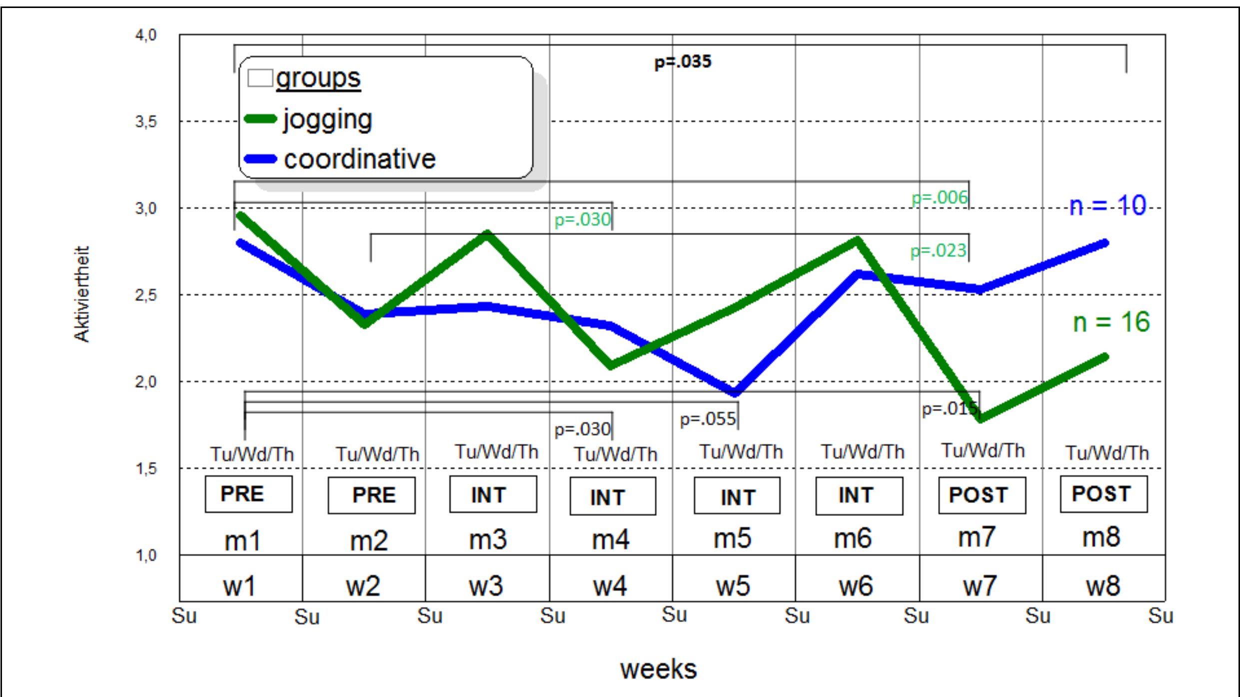


Figure 39: “Aktiviertheit” in both groups over a period of 8 weeks in a total sample of N= 26 Significant p-values of overall (in black) and univariate paired t-test comparison (in colour)

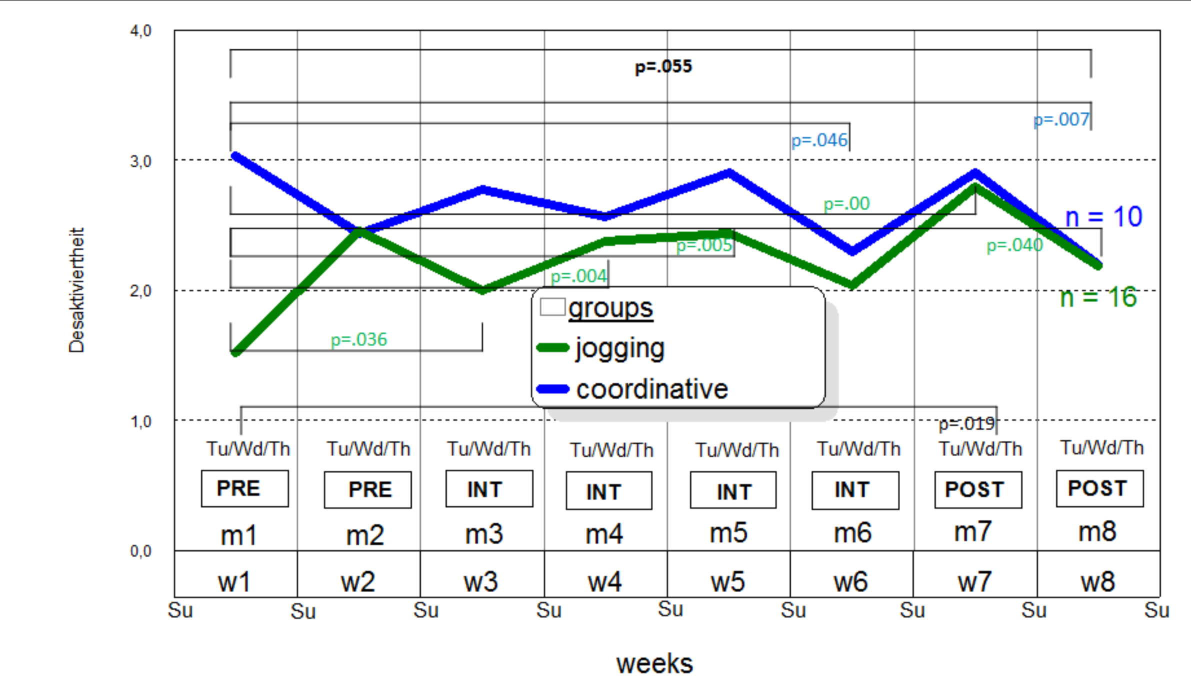


Figure 40: “Desaktiviertheit” in both groups over a period of 8 weeks in a total sample of N= 26 Significant p-values of overall (in black) and univariate paired t-test comparison (in colour)

3.3.3 Mehrdimensionale Körperliche Symptomliste (MKSL)

A significant interaction effect was observed in “Allgemeine körperliche Entspannung” (p= .012) and is shown in Figure 41. Univariate paired t-test comparisons only showed a significant increase in the coordinative group between m5 and m2/m3/m7 (p<.05).

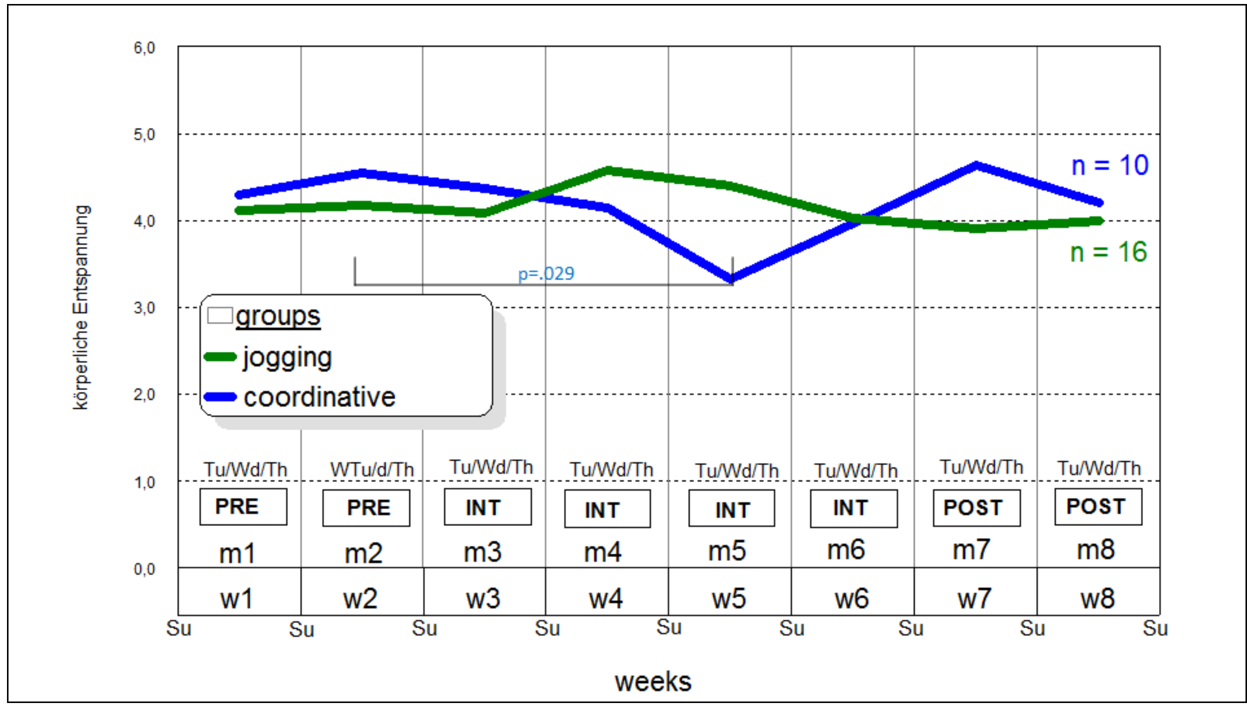


Figure 41: “Körperliche Entspannung” in both groups over a period of 8 weeks in a total sample of N= 26 One univariate significant p-value of the coordinative group in blue

4 Discussion

In sport scientific research, heart rate variability (HRV) indices over time and frequency domain have gained increasing interest, examining the impact of physical activity or high-performance training on autonomic modulation. It is well-established that endurance training in terms of short to long time interventions with moderate to vigorous intensity in healthy adults result in significant alterations of HRV indices (Hottenrott, Hoos & Esperer 2006)(Hottenrott, Hoos & Esperer 2006, Sant'Ana et al. 2011, Garber et al. 2011, Garber et al. 2011)(Hottenrott, Hoos & Esperer 2006). Evidence for the positive influence of short-term interventions on autonomic activity do exist in current literature und show a positive correlation (Nummela et al. 2010, Iwasaki et al. 2003, Lee, Wood & Welsch 2003). (Lee, Wood & Welsch 2003) reported on changes in the cardio-autonomic profile after eight sessions of vigorous to high-intensity training over only 2 weeks. The investigations on the impact of physical activity on cardio-autonomic parameters in children and adolescents are poor and not transparent enough to make firm conclusions (Baquet, van Praagh & Berthoin 2003, Mandigout et al. 2002, Nagai et al. 2004, Franks, Boutcher 2003, Vinet et al. 2005, Gamelin et al. 2009). In children, the autonomic nervous activity is dependent on the maturation state and the gender, leading to different adaptations after physical activity. These adaptive processes may be related to mechanical and neural alterations (Lenard et al. 2004, Silvetti, Drago & Ragonese 2001). Given the high individual spread of HRV indices, a sample composed completely of girls was chosen to avoid the gender difference and great care was taken to standardise conditions for measurements with regard to circadian influences (menstruation cycle…).

Recordings during sleeping conditions may allow better discrimination of changes in the ANS (Hynynen et al. 2010, Pichot et al. 2002) because sleep seems to be the most important period for suspension of consciousness during which processes of restoration and rest occur. To maintain health and homeostasis, the reparative, cognitive and regenerative functions of sleep are important (Brosschot, Van Dijk & Thayer 2007, Murali, Svatikova & Somers 2003, Moser, Kripke 2013). The cardiovascular response to physical activity gives coherent information on the autonomic recovery during sleep and should be better involved in sport scientific research. Data about the response of autonomic regulation to physical activity during sleep are still lacking in great measure. The aim of the present study was to analyse the impact of two sport interventions with the same intensity, frequency and duration on

autonomic recovery during sleep and to point out possibly different autonomic developments between the groups.

4.1 Significant impact of physical activity on autonomic modulation during sleep

Although both groups increased their level of fitness, a significant decrease of the HR during the day (p=.040) and during sleep (p=.045) could only be observed in the jogging group. After a significant increase of HR in both groups (p=.004) as response to the trainings impulse, also observed in the investigation of (Hynynen et al. 2010), the decrease in the jogging group until the end of the study was of a similar magnitude in altered resting HR as reported by (Wilmore et al. 2001). In this regard, the findings of (Lee, Wood & Welsch 2003) also correspond to our results indicating a decrease in resting HR after a short period. The coordinative group reacted to the sportive stimulus with an increase of HR during the whole intervention period and was able to find a physiological compensation during the post period, shown in a decline of HR values.

Respiratory patterns also have an important influence on HRV indices and should be taken into consideration. The use of controlled breathing improves the reproducibility of test findings and makes a quantitative comparison possible (Rajendra Acharya et al. 2006a, Kabir et al. 2010, Cysarz, Bussing 2005). In the present study, analysis of the Pulse-Respiratory-Quotient (PRQ) revealed a significant decrease (p=.016). From the pre- to the intervention period, an increase of PRQ in both groups (p=.028) can be observed (the ON-effect of the training is mentioned on the following pages), showing a similar increase to that of HR parameters.

Another finding applies to the significant main effect of the total frequency domain (p=.028). The coordinative group could decrease the TOTrr (p=.06) from the beginning to the end of the study, indicating markers of quiet sleep (Stein, Pu 2012b), whereas the TOTrr of the jogging group developed, especially during the intervention period, in a different way: the jogging group raised the TOTrr during the intervention until m4, demonstrating a higher activity potential and unquiet sleep. Although there was no significant interaction effect, a conclusion on different response to physical activity can be drawn. This divergent development leads to the next main finding, seen in significant interaction effects of the nocturnal recovery.

4.2 Autonomic sleep quality

4.2.1 Different impacts of both training interventions on autonomic sleep quality

Bouts of physical activity determine modifications of the ANS during sleep. As sleep constitutes a condition free from external disruptive events, current literature has proposed that HRV parameters may provide reliable information on the sympatho-vagal balance as a response to physical activity (Hynynen et al. 2010, Nummela A et al. 2010, Buchheit et al. 2004). Sleep is characterized by large variations in autonomic balance influenced by different sleep cycles (REM, NREM) (e.g. chapter 1.2.2), therefore, all night recordings were considered to ensure optimal conditions for HRV analysis.
The ratio between LF (predominating sympathetic) and HF (vagal), seen in the VQ, revealed a significant interaction (p=.020), pointing out the different compensation of both groups. The coordinative training led to a decrease in VQ values indicating a high potential of relaxation during sleep after the training had begun. Less nocturne recovery was achieved by the jogging group showing a high level of activation in the first week of training (p=.006). After the intervention period, the jogging group achieved vegetative polarisation. This divergent development confirms values of LF (interaction: p= .028) that showed the highest level in the jogging group during the first week of intervention, indicating restless sleep.

One of the main findings of this study, suggesting that physical activity has an impact on the sympatho-vagal balance, can be found in investigations with adults (Hautala et al. 2001, Pichot et al. 2000), but may not be exactly approved in research with children or adolescents(Mandigout et al. 2002, Gutin et al. 1997). As literature about the development of nocturnal HRV indices in children is scarce, a sufficient basis for comparison cannot be ensured. (Gutin et al. 1997, Gutin et al. 2000) reported that, in general, physical activity can induce favourable changes in the sympatho-vagal balance in obese children.
The result that coordinative training provides a high potential of relaxation, whereas the jogging group was exposed to a high level of activation during sleep cannot be compared with current literature. To the best of my knowledge, this is the first study investigating the different impact of two endurance trainings with the same intensity, duration and frequency on autonomic sleep quality. Study designs of investigations on nocturnal HRV parameters mostly include interventions with jogging or cycling, but hardly coordinative training. (Nagai et al. 2004) found that a long term moderate-intensity coordinative program increased LF and HF power of children, indicating an enhancement of the sympatho-vagal balance.

Another interesting outcome was the shift of the sympatho-vagal balance with a predominance of the sympathetic modulation in the coordinative group during sleep. The sympathetic tone took over the withdrawing parasympathetic activity as response to the training. (Hynynen et al. 2010) reported the highest decrease up to 66% of HF values as response to training, but the reasons for this development during the intervention period remain speculative. (Hautala et al. 2001) equalised the decrease of HF as response to the training with a low cardio-respiratory profile, while (Hynynen et al. 2008, Hynynen et al. 2010) pointed out that the adaptability of the ANS is definitively not only related to the aerobic capacity and referred to the "autonomic resource hypothesis": this hypothesis states that the modulation of ANS varied between humans as a function to resources. Higher basal levels of HF values are related to a greater response to external stimuli than lower levels. (Buchheit et al. 2004) indicated that a low respiratory rate could also provoke a shift toward the sympathetic predominance.
Other investigations (Sandercock, Bromley & Brodie 2005, Buchheit et al. 2004, Buchan et al. 2011a, Buchan et al. 2011b) reported on an increase of vagal activation during training periods; (Pichot et al. 2002) found out that, especially in young subjects, high and low bouts of physical activity could shift cardiac autonomic activity in the direction of higher vagal modulation. The data of the jogging group, in contrast to the coordinative group, confirmed the increase of HF values during the training period by trend.
During the last week of the intervention period, the sympatho-vagal balance returned to the basal level in both groups. This development agrees with current literature (Hautala et al. 2001), indicating that altered autonomic levels of balance may reach the basal level after a compensation to external stimuli.(Iwasaki et al. 2003) adverted to the bell-shaped graphic relationship between exercise and HRV indices and explained the return to the basal level.

Analysis of the autonomic sleep quality index (SQidx) with its nearly significant interaction ($p=.103$) confirms the divergent development of both groups, pointing out that especially at the beginning of the training the coordinative group was able to improve autonomic sleep recovery, whereas the sleep quality of the jogging group developed in a negative way.

Based on the lack of consistent nocturnal HRV responses in children or adolescents, it is probably premature to make firm conclusions about the immediate influence of physical activity on the autonomic sleep recovery. Nevertheless, these findings indicate the high sensitivity of HRV indices to physiological adaptations of the ANS during sleep and give

clear information on the disturbance of homeostasis, especially induced at the beginning of the intervention period.

4.2.2 ON-effect of the sport interventions during sleep

The interims between pre- to intervention period were especially of common interest with the main focus on the response of the ANS on the sportive stimuli.

Based on the HR responses during sleeping conditions, it is evident that throughout the beginning of the intervention the capacity of the heart was challenged in both groups. As the external stimulus was high enough, physiological adaptive processes appeared and can be seen in a significant overall increase of HR (p=.004) from the pre- to intervention period. This ON-effect could also be observed in other prevailing investigations (Hynynen et al. 2010, Nummela A et al. 2010, Buchan et al. 2011a). (Hynynen et al. 2008) reported on an augmented nocturnal HR of 7% after hard training compared to easy training days, indicating that intensity seems to be a key factor in the modulation of the heart rate and the ANS.

To specify the response of the ANS to physical activity, the results of the respiratory sinus arrhythmia (RSA), a marker of vagal activity, give further information on the parasympathetic interaction. In the literature, the simple magnitude of RSA is assumed as a valid index of vagal outflow and has gained attention over the years (Eckberg 2003, Grossman, Wilhelm & Spoerle 2004, Grossman, Taylor 2007). Vagal suppression (decrease in parasympathetic activity) always reflects engagement with external challenges and offers an efficient coping response (El-Sheikh, Buckhalt 2005). This adaptive response of the parasympathetic activity is well demonstrated by the significant decrease (p=.010) of vagal activation in both groups. Developments of nocturnal RSA after physical activity are not well established, but (Grossman, Wilhelm & Spoerle 2004, Grossman, Taylor 2007) reported on a systematic decrease in RSA as response to increased activity during the day. Research has focused on the relationship between RSA and sleep quality (Cysarz, Bussing 2005, Irwin et al. 2006, El-Sheikh, Erath & Keller 2007). (Elmore-Staton et al. 2012) found out that higher resting RSA values predict both a higher sleep efficiency and quality in children and adolescents.

4.3 ON effects during circadian variations

Besides HRV indices during sleep, the analysis of parameters during circadian variations (difference between day and sleep, meaning fluctuations that occur during the day) have to be taken into consideration because a more transparent conclusion can be drawn by correlating values during day and night. The 24-h variations in physiological functions are controlled by a body clock (e.g. chapter 1.2) and are influenced by sleep, physical activity and environmental events (Atkinson, Jones & Ainslie 2010). Investigations on circadian rhythms in the response of physiological adaptation to physical activity are mostly not incorporated in sport scientific research. (Sugawara et al. 2001)´s investigation is one of the few examining the circadian variations of post-exercise vagal reactivation in different chronotypes (morning and evening-type). They found out that the sleep-wake cycle may affect the circadian rhythm of the parasympathetic reactivation, having regard to genetic factors. This means for the present study that analyses of the ANS during circadian variations remain important as physical activity influences the sleep cycle and vice versa.

The highly significant interaction of circadian LF values (p=.007) during pre- to intervention period is a representative example for a vitalisation in the coordinative group based on an increase in wakefulness and a decrease during sleep, leading to better circadian variations. The coordinative group, contrary to the jogging group, showed dipping structures during the night. In current literature, the dipping phenomenon, especially in blood pressure, has been examined with major findings that the lack of nocturnal BP decrease, called non-dipping, is associated with a higher cardiovascular risk (Biaggioni 2008, Okutucu et al. 2010). (Eguchi et al. 2009) pointed out that even when HR does not exhibit the typical nocturnal decline, the risk of future cardiovascular disease was shown to be 2.4 times higher in hypertensive patients.

In addition, the nearly significant interaction of circadian HF values (p=.068) indicates that the coordinative group was able to augment the level of vagal modulation during the day and not during sleep, leading to an increase in circadian variations. Vagal modulation in the jogging group decreased during sleep and day between pre- to intervention period.

4.4 The influence of physical activity on cardio-respiratory fitness

4.4.1 Significant increase of the fitness level after a short-term intervention

The study design of three 30-minute bouts per week over a period of 4 weeks with vigorous-intensity physical activity was chosen according to the Physical Activity Recommendations for Youth (U.S. Department of Health and Human Services. 2008, O'Donovan et al. 2010), recommending that healthy adolescents should be active one hour per day and should achieve a vigorous aerobic performance at least three times a week. A training over 30 minutes seems to be a suitable stimulus and can be equalised to a 60-minute session (Sant'Ana et al. 2011). Current literature (Baquet, van Praagh & Berthoin 2003, Buchan et al. 2011a, Buchan et al. 2011b, Buchheit et al. 2007) supports the adolescent need for vigorous physical activity, considering that moderate physical activity has an impact on health-related indexes, but higher intensity seems to be associated with improved cardiac activation. (Mandigout et al. 2002) reported an increase of HRV parameters after vigorous-intensity training in young participants. The intensity seems to be a determining factor in training design, obtaining significant increase in the aerobic fitness level in adolescents.

The present study showed that 26 healthy female pupils substantially augmented their fitness level ($p=.001$) after twelve 30-minute training sessions with vigorous intensity throughout four weeks, independent of the intervention. Both intervention programs made a contribution to a better cardio-respiratory fitness profile in healthy adolescent girls. In general, it is difficult to previously determine that a 4-week intervention period with vigorous intensity augments the participants´ fitness levels, because even after a long-lasting training the development of endurance is not exactly predictable; there is strong evidence for heterogeneity in the responsiveness to bouts of physical activity. Different determinants like the pre-training level or family genetic disposition have influence on human response to regular physical activity (Bouchard, Rankinen 2001). Some studies (Nummela A et al. 2010, Kiviniemi et al. 2007) analysed the improvement of aerobic capacity after a short training period and came to the conclusion that intervention programs of 4 weeks are sufficient to produce positive training effects. The present study agrees with the key findings of current literature, indicating that short-term training improves the level of endurance.

4.4.2 Individual response to the interventions

The 20-meter shuttle run (Leger et al. 1988) is a valid test to assess cardio-respiratory fitness. The test is easily conducted with a large number of participants during a minimal time period. Comparing the results of the present study with the outcomes of the HELENA study (Ortega et al. 2011), where the average fitness levels of 3,428 adolescents were determined, it can be said that the female participants from Graz reached higher shuttle run stages (5.2± 1.3) than the average European female adolescents do (4±2). Nevertheless, the classification into trained (N=5), average (N=6) and untrained (N=15) girls shows that, in summary, the sportive level is low in comparison to current literature (Baquet, van Praagh & Berthoin 2003). It was assumed that all untrained participants (N= 15; 57,7%) might have increased their shuttle run stage up to one higher level, but in fact 4 untrained girls (28,6%) did not augment their fitness. Three average girls and 1 trained female pupil were also not able to improve the cardio-respiratory fitness after the intervention. Current literature suggests that response to an aerobic training vary from none to an increase of 40% in the cardio-respiratory fitness profile of sedentary adults (Bouchard, Rankinen 2001, Hautala, Kiviniemi & Tulppo 2009, Hautala et al. 2003). Normative references about children and adolescents show an improvement of cardio-respiratory fitness of about 5-6% after sports intervention (Baquet, van Praagh & Berthoin 2003) and agree with the cardio-respiratory increase of 5.8 % in the present study. Nevertheless, there is a notable lack of studies examining the improvement of aerobic fitness in adolescent girls.

The different response to the training remain unclear, but may be related to different genotypes, an individual sportive background during the past years and the functioning of the ANS(Bouchard 2012). (Hautala, Kiviniemi & Tulppo 2009) has shown that an increased cardiac vagal modulation independent of age and gender is associated with a good cardio-respiratory profile. Following this fact, the functioning of the autonomous nervous system is a determinant of training response, meaning that the cardiovascular system with high vagal functions has a better capacity to adapt to external stimuli.

The intensity and duration of both intervention programs were adequate for positive training results, however with a spread of response to the training. The present study confirms the significant increase of cardio-respiratory fitness that occurs after 4 weeks of endurance training with vigorous intensity. It would be interesting to know if the intervention program

were conducted over 2 months or longer, would the cardio-respiratory fitness have augmented at least up to one shuttle run stage in all participants.

4.5 Accordance of psychological to physiological outcomes concerning sleep

The present study has shown that physical activity could be a robust stimulus for the autonomic modulation during the night that may affect the sleep quality. Bouts of 30-minute sessions three times a week are appropriate to alter the cardio-autonomic indices. The ON-effect of the training can be observed in a divergent development of HRV parameters and also agrees with the sub-item "aktuelle Schlaferholung," indicating an increase in the coordinative (p=.015) and a decrease in the jogging group from pre- to intervention period. "Aktuelle Schlaferholung" (p=.001) and "aktuelle Schlafbewertung" (p=.001) over all 8 weeks result in a significant positive main effect, pointing out that the subjective valuation was higher and do not totally agree with the development of cardio-autonomic parameters. The highest values of the mentioned sub-items were achieved at the end of the intervention period, which showed that physical activity, independent of coordinative or jogging training, contributes to a better subjective sleep profile. These outcomes agree with current literature (Caldwell et al. 2011, Arcos-Carmona et al. 2011, Caldwell et al. 2009), revealing an improvement of subjective sleep quality, measured by questionnaires. The result of the sub-item "Erholsamer Schlaf" in the EBF questionnaire indicates that before a rise in subjective sleep recovery happened, the sportive stimulus led to a decrease until the second week of training in the coordinative group and until the third week of training in the jogging group.

4.6 Overview of the hypothesis and the results

This overview summarizes all hypothesis and results of the present study: research questions can be found on page 58 and the hypothesis on page 81.

Hypothesis are ++ confirmed/ + partly confirmed /--are rejected

Table 28: Overview of hypothesis and results of the present study

	confirmed				
Hypothesis	yes	partly	no	table/ figure	page
A.) Characteristic of the autonomic sleep quality	++				
A1. During the intervention period, the autonomic nervous system reacts on the induced stimulus of physical activity	++				
A2. The two types of training differ in their impact on nocturnal cardio-autonomic parameters during the intervention period	++				
A3. The autonomic sleep quality augments in both groups during the intervention period			--		
B.) Characteristic of physical actvity	++				
B1. after 4 weeks of training with vigorous intensity, the girls´ fitness augments	++				
B2. especially the untrained pupils reach one higher shuttle after the intervention period		+			
B3. 4 weeks with regular bouts of vigorous physical activity are enough to see changes in the cardio- autonomic profile during circadian variations	++				
C.) Accordance between qualitative and quantitative measures		+			
C1. The outcomes of the subjective psychological sleeping parameters confirm the values of the cardio-autonomic parameters		+			
C2. the impact on psycho-social and mental processes is little during the intervention period	+				

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List of Figures

Figure 1: Distribution of VO_{2max} (mL.kg^{-1}.min^{-1}) values in girls and boys aged between 6-18 years. The dots represent mean values from actual studies, adapted from (Plowman, Smith 2008, p.367) 14

Figure 2: Classification of relative $VO_{2\ max}$ values of females aged between 10-80 years into excellent to very poor trained, adopted from (Shvartz, Reibold 1990) in http://www.aminoz.com.au/beep-test-calculator-shuttle-calc-8.html 15

Figure 3: Steady state of cardiac output within 2 minutes after the onset of aerobic exercise 20

Figure 4: Steady state of systolic blood pressure (SBP) and mean arterial pressure 20

Figure 5: Possible relationships between physical activity (PA) during youth and health during adulthood, adapted from (Twisk 2001, p.619) 23

Figure 6: Austrian Physical Activity Guidelines for Children and Adolescents, adapted from (Titze et al. 2010) 32

Figure 7: The two process model of sleep: bold lines (=the homeostatic process) accumulate during wakefulness and decline during sleep. The circadian process regulates the timing of sleep; this means that sleep pressure in the upper threshold initiates sleep and sleep pressure in the lower treshold induces wakefulness, adapted from (Crowley, Acebo & Carskadon 2007, p.606) 35

Figure 8: This histogram shows the sleep cycles of a 14- years old girl, adapted from (Carskadon, M.A., & Dement, W.C 2011, p.11) 39

Figure 9: Possible effects of exercise on sleep quality with the classification into acute, acute but subsequent chronic and chronic components, adapted from (Uchida et al. 2012, p.48) 51

Figure 10: ChronoChord records heart rate and respiratory correlated parameters over 24-hours with a high standard of RR identification 67

Figure 11: ChronoCardioGramm with 8 informative parts of HRV analysis 70

Figure 12: ChronoCardioGramm of a healthy young man during a bad night on the left side and a good night on the right side (data from University of Freiburg, Prof. Dr. Riemann) 72

Figure 13: Example items of the EBF questionnaire 77

Figure 14: An example item of the MKSL questionnaire 77

Figure 15: Example items of the BSKE questionnaire 78

Figure 16: Development of the heart rate (HR) in a sample of N= 26 during sleep 84

Figure 17: Development of the Pulse-Respiratory Quotient (PRQ) in a sample of N= 26 during sleep Significant p- values of overall (in black) and univariate paired t-test comparisons (in colour) 86

Figure 18: Development of the total variability (TOTrr) in a sample of N= 26 during sleep 88

Figure 19: Development of the Vegetative Quotient (VQ) in a sample of N= 26 during sleep 90

Figure 20: Index of LFhf during sleep in a sample of N=26 91

Figure 21: Development of the Sleep Quality Index (SQidx) in a sample of N= 26 93

Figure 22: "Aktuelle Schlaferholung" in both groups in a total sample of N= 26 95

Figure 23: "Aktuelle Schlafbewertung" in both groups in a total sample of N= 26 97

Figure 24: "Schlaflänge" in both groups over 8 weeks in a total sample of N= 26 98

Figure 25: Development of the respiratory sinus arrhythmia (RSA) in a sample of N= 26 during sleep Significant p-values of overall (in black) and univariate paired t- test comparison (in colour) 100

Figure 26: Development of the Low Frequency (LFhf) during sleep and day in the jogging group (N=16) in green and in the coordinative group (N=10) in blue 102

Figure 27: Quotient (day/sleep) of LFhf expressed as Index in the jogging (n=16) and in the coordinative Group (N= 10) 103

Figure 28: Cirdcadian variations of Low Frequency (LFhf) in a sample of N= 26 104

Figure 29: Development of the High Frequency (HFhf) during sleep and day in the jogging group (N= 16) and the coordinative group (N=10) 105

Figure 30: Quotient (day/sleep) of HFhf expressed as Index in the jogging (n=16) and in the coordinative Group (N= 10) 106

Figure 31: Circadian variations of High Frequency (HFhf) in a sample of N= 26 107

Figure 32: Development of the Heart Rate (HR) during sleep and day in green for the jogging group (N= 16) with a significant main effect during day (p=.040) and during sleep (p=.045), in blue for the coordinative group (N= 10) without significance 109

Figure 33: Shuttle run levels before and after the intervention in the jogging group (N= 16) with a main effect (p= 0.003) and in the coordinative (N=10) group with a main effect (p= 0.053) 110

Figure 34: Shuttle run levels split off into untrained (N= 15)/ average (N= 6)/ trained (N= 5) participants before and after the intervention with a significant main effect in the untrained (p= 0.0) and trained (p= 0.027) girls 110

Figure 35: Amount of physical activity during 8 weeks in a sample of N= 26 112

Figure 36: Soziale Beanspruchung 114

Figure 37: Soziale Erholung 114

Figure 38: Erholsamer Schlaf 114

Figure 39: "Aktiviertheit" in both groups in a total sample of N= 26 116

Figure 40: "Desaktiviertheit" in both groups in a total sample of N= 26 116

Figure 41: "Körperliche Entspannung" in both groups in a total sample of N= 26 117

List of Tables

Table 1: Classification of exercise intensity in $\%HR_{max}$, $\%VO_{2\,max}$ and METs in healthy adults, adapted from (Howley ET 2001, p.367) 16

Table 2: Cardiac adaptions in dependence of the intensity adapted from (Plowman, Smith 2008, p.362) 22

Table 3: The autonomic nervous system (ANS) with its cardiovascular functions, adapted from (MacArdle, Katch & Katch 2006, p.373) 43

Table 4: Main findings of the relationship between autonomic modulation during sleep and physical activity in adults and children 55

Table 5: Demographic and fitness data of all participants (N= 31) 60

Table 6: Sample space of all participants (N=31) during week 1- week 4 with an itemization of psychological and physiological data 61

Table 7: Sample space of all participants (N=31) during week 5- week 8 with an itemization of psychological and physiological data 62

Table 8: Experimental design over 8 weeks with N= 31 64

Table 9: Measured variables over a period of 8 weeks in a sample of N= 31 64

Table 10: Time of all measurements during 8 weeks 66

Table 11: A classification of shuttle run stages in trained average and untrained among female adolescents 73

Table 12: Time of measurements of all questionnaires during 8 weeks in a sample of N= 31 74

Table 13: Activity protocol for the whole day during HRV measurements 75

Table 14: Descriptive values of the heart rate (HR) in a sample of N= 26 during sleep 83

Table 15: Descriptive values of the Pulse-Respiratory Quotient (PRQ) in a sample of N= 26 during sleep 85

Table 16: Descriptive values of total variability (TOTrr) in a sample of N= 26 during sleep 87

Table 17: Descriptive values of the Vegetative Quotient (VQ) in a sample of N= 26 during sleep 89

Table 18: Descriptive values of the LowFrequency (LFhf) in a sample of N= 26 during sleep 91

Table 19: Descriptive values of the sleep quality index (SQidx) in a sample of N= 26 92

Table 20: Descriptive values of "Aktuelle Schlaferholung" in a sample of N= 26 94

Table 21: Descriptive values of "Schlafbewertung" in a sample of N=26 96

Table 22: Descriptive values of "Schlaflänge" in a sample of N= 26 98

Table 23: Descriptive values of respiratory sinus arrhythmia (RSA) in a sample of N= 26 during sleep 99

Table 24: Circadian variations of Low Frequency (LFhf) in a sample of N= 26 101

Table 25: Levels of the "shuttle run" in a sample of N= 26 (time (p)= .001/ time* group= .497/ group= .440) on the left side and converted into VO_{2max} values on the right side 109

Table 26: Classification of trained/ average/ untrained girls in a sample of N= 26 109

Table 27: The total amount of physical activity in a sample of N= 26 expressed in METs through the IPAQ questionnaire; (p: time=.00, time*group=.223, group=.450) 111

Table 28: Overview of hypothesis and results of the present study 127