Heart rate variability at the anaerobic threshold between performance and non-performance oriented subjects

Including reliability of HRV

Master Thesis

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by
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Declaration

I declare that I have developed and written the enclosed Master Thesis completely by myself, and have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked. This work was not used in the same or in a similar version to achieve an academic grading or is being published elsewhere.

St. Pölten, 14.05.2019 .... Jeannine Vodicka ....

Place, Date Signature

Preface

A huge thank you goes to my former coach, Kristof Wöginger, who helped me a lot with brainstorming and finally finding an idea for this thesis.

Another thank you is for Christoph Feigl, who jumped in at the last minute to carry out the professional Conconi test evaluation.

Many thanks to my participants who took the time to support me with this master thesis. They sweated to their limits and thus enabled me to get something out of this study.

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Abstract

Introduction

According to the literature, most of the available studies have already established that high heart rate variability can protect against coronary heart disease and that heart rate variability can be increased through regular training and endurance training. One of the goals of this work was to investigate a possible difference in heart rate variability at the anaerobic threshold between trained and untrained subjects. The aim of this investigation is to examine whether the heart rate variability is actually increased by regular endurance exercises. Since the measurement of heart rate variability in the field of sports and here in particular in the training control area has become more important, it was a further goal to find out the reliability of heart rate variability during a resting situation and a standardized treadmill ergometric test. The information obtained could thus be useful for health promotion and the creation of training concepts.

Question

Research Question 1: How reliable is heart rate variability during a “change of position test” and treadmill ergometric exercise in performance-oriented subjects and a peer group? *Research Question 2:* At the anaerobic threshold, can a difference in heart rate variability be found among trained and untrained subjects?

Method

In this pilot study, 5 trained and 5 untrained male subjects aged 30 to 35 years performed two different tests: a 15-minute change of position test and a treadmill ergometric test according to the Conconi test scheme. Both tests were repeated second times by each subject after a one-week break.

Results

This study can not completely confirm the reliability of the heart rate variability. At the anaerobic threshold, no statistically significant difference between trained and untrained subjects was found. However, also at the anaerobic level, a *visual difference* between both groups of subjects could be determined.

Keywords

Heart rate variability, Reliability, Conconi, Anaerobic Threshold.

Kurzfassung

Einleitung

Beinahe alle bislang vorliegenden Studien haben gezeigt, dass eine hohe Herzratenvariabilität vor koronaren Herzerkrankungen schützen kann und dass die Herzratenvariabilität durch regelmäßiges Training sowie Ausdauertraining erhöht werden kann. Eines der Ziele dieser Arbeit war es, einen möglichen Unterschied der Herzfrequenzvariabilität an der anaeroben Schwelle zwischen trainierten und untrainierten Personen zu untersuchen. Mit dieser Untersuchung soll überprüft werden ob die Herzfrequenzvariabilität durch vermehrtes Ausdauertraining tatsächlich erhöht ist. Da die Messung der Herzratenvariabilität im Bereich Sport und hier im speziellen im Trainingssteuerungsbereich an Bedeutung gewonnen hat, war ein weiteres Ziel dieser Arbeit, die Reliabilität der Herzfrequenzvariabilität während einer Ruhesituation und einer standardisierten ergometrischen Belastungsuntersuchung auf dem Laufband herauszufinden. Die gewonnenen Informationen könnten somit der Gesundheitsförderung und der Erstellung von Trainingskonzepten dienlich sein.

Forschungsfrage

Forschungsfrage 1: Wie reliabel ist die Herzfrequenzvariabilität bei einem "Lagewechsel-Test" und einem Laufband ergometrischen Belastungstest bei leistungsorientierten Probanden und einer Peergroup? *Forschungsfrage 2:* Kann an der anaeroben Schwelle ein Unterschied in der Herzfrequenzvariabilität bei trainierten und nicht trainierten Probanden festgestellt werden?

Methodik

In dieser Pilotstudie führten 5 ausdauertrainierte und 5 untrainierte männliche Probanden im Alter von 30 bis 35 Jahren zwei verschiedene Tests durch. Ein 15-minütiger Lagewechseltest und eine ergometrische Belastungsuntersuchung auf dem Laufband nach dem Conconi-Testschema wurden durchgeführt. Beide Tests wurden von jedem Probanden nach einer einwöchigen Pause ein zweites Mal wiederholt.

Ergebnisse

Diese Studie kann die Reliabilität der Herzfrequenzvariabilität nicht vollständig bestätigen. An der anaeroben Schwelle wurde kein statistisch signifikanter Unterschied zwischen ausdauertrainierten und untrainierten Probanden gefunden. An der anaeroben Schwelle konnte allerdings ein *visueller Unterschied* zwischen beiden Probandengruppen festgestellt werden.

Schlüsselwörter
Herzfrequenzvariabilität, Reliabilität, Conconi, Anaerobe Schwelle.

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List of abbreviations

ANS	autonomous nervous system
AT	anaerobic threshold
ECG	electrocardiogram
et al.	et alii = and others
FFT	fast fourier transformation
HF	high frequency (parasympathetic)
HR	heart rate
HRV	heart rate variability
Hz	hertz
ibid.	ibidem = same as the previous citation
LF	low frequency (sympathetic and parasympathetic)
LF/HF	low frequency/high frequency-ratio %
ms	milliseconds
NN	normal-to-normal
PSNS	parasympathetic nervous system
RSA	respiratory sinus arrhythmia
SDNN	standard deviation of all NN intervals (total variability: sympathetic and parasympathetic)
SNS	sympathetic nervous system
TP	total power (total variability)

1 Introduction

According to the latest WHO data published in 2017, coronary heart disease is once again the leading cause of death in Austria, responsible for 28.06% of total deaths in 2017 (Weltgesundheitsorganisation, 2017). However, researchers found out that regularly exercising or performing endurance training can prevent sudden infarct deaths. This is proven to increase heart rate variability (HRV), and high HRV thus protects against coronary heart disease (Hull et al., 1994).

Since the 1990s, HRV has been established as a marker of autonomic regulation in cardiology and diabetology. In the last few years, HRV has increasingly attracted the interest of sport scientists, psychologists and biologists. This is evidenced by a significant increase in publications in scientific journals dealing with HRV. Newer measurements and analysis methods allow the use of HRV in answering progressively complex questions. As stated by Hottenrott (2011), a very large range of HRV applications are currently being developed in the area of systematic biofeedback, which makes targeted use of the close correlation between respiration and heart rate modulation. This biofeedback method is used not only in the psychosomatic treatment of stress, depression and anxiety, but increasingly also in occupational health management and in sports.

Particularly in the field of training supervision, HRV could be an important assessment criterion for regeneration processes of athletes. It can help as a sensitive marker of fine-tuning individual training loads. With the help of HRV measurement, health-promoting training is guaranteed (Hottenrott, 2006).

HRV reflects the activity of the autonomic nervous system and characterizes the variation from heartbeat-to-heartbeat (= RR interval). Figure 1 shows an electrocardiogram (ECG), which is based on a simple pattern and comprises three waves called P, QRS (a wave complex) and T. It can also be seen in the figure that RR intervals are built up from the intervals between successive R waves (RR (1), RR (2)). A high HRV can be the sign of good adaptation and, consequently, a healthy organism. A low HRV is associated with heart attacks and diabetes and can be visible in "lifestyle" diseases as well as in stress-related illnesses (Vanderlei, Pastre, Hoshi, Carvalho, & Godoy, 2009).

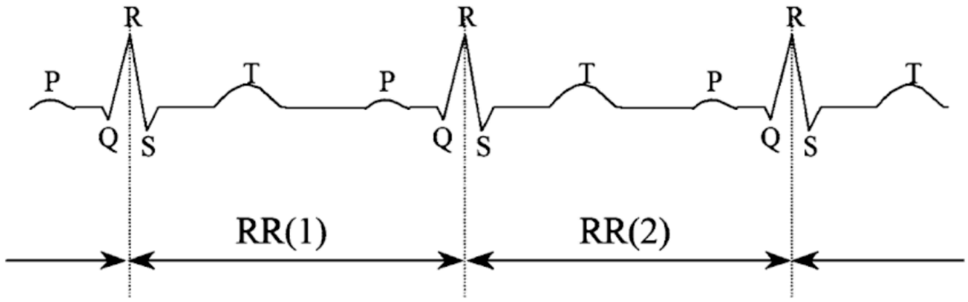


Figure 1: Electrocardiogram: RR intervals are constructed from the intervals between successive R-waves (Khandoker, Karmakar, Brennan, Voss, & Palaniswami, 2013).

Through the analysis of the heartbeat dynamics during increasing stress, statements about the vegetative control of the heart activity can be made. Findings suggest that people with lower aerobic physical capacity also have lower heart rate variability and that exercise increases the HRV in athletes (Jiménez Morgan & Molina Mora, 2017, Hull et al., 1994). Hence, the assumption is that there is a difference in heart rate variability among trained and untrained individuals with a treadmill-induced ergometric load.

This study documents HRV during intensive endurance exercise (Conconi test on a treadmill), with the aim of finding out a possible difference in heart rate variability in the anaerobic threshold in trained and untrained individuals. The anaerobic threshold (AT) is generally regarded as the point at which lactic acid (a by-product of energy glucose production) quickly accumulates in the blood. This happens because lactic acid cannot be removed fast enough and recombined with other molecules to generate more energy. In comparison, if an athlete trains in the aerobic area, his body has enough oxygen available to ensure the oxidative combustion of glycogen and fatty acids (Anosov, Patzak, Kononovich, & Persson, 2000). In addition, the data should also give more information on how reliable HRV during a resting situation and exercise ergometric performance is. According to Hottenrott (2006) the obtained information might be beneficial to health promotion or to the creation of training concepts.

2 Theoretical Background

In this chapter, the theoretical background regarding heart rate variability is described, such as the definition, history and more in-depth information about HRV. Overall, it gives an overview of heart rate variability and its function during exercise.

2.1 Definition of heart rate variability

If one considers the distance between two heartbeats, more precisely between two RR intervals on the ECG, a heart physiologically does not beat exactly regularly but varies the RR interval length minimally from beat to beat. These millisecond interval changes are referred to as heart rate variability (see Figure 2). HRV describes the physiological ability of an organism to adapt the time interval between two heartbeats as needed (Hottenrott, 2002, p. 9-27).

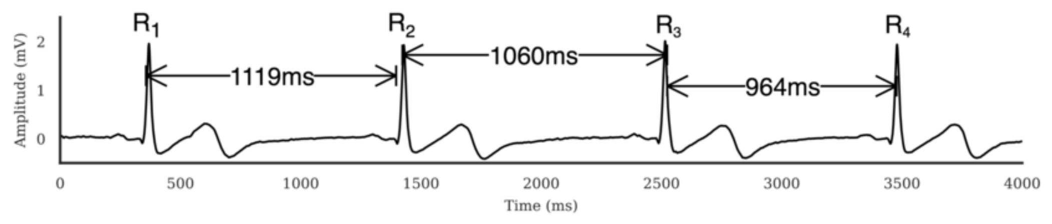


Figure 2: Interval changes between two RR intervals (Nkurikiyeyezu, Suzuki, & Lopez, 2017).

Vanderlei et al. (2009) states that several of control circuits in the human body such as sympathetic and parasympathetic (vagal) influences respiration, thermoregulatory processes and hormonal systems are involved in this adaptation. The HRV reflects these control circuits. This allows detection and qualitative description, in which high HRV generally indicates good adaptation and subsequently a healthy organism. As such, a low HRV is often a sign of abnormal and inadequate adaptation of the autonomic nervous system (ANS) (Vanderlei et al., 2009). For a better understanding of ANS, this specific type of nervous system will be explained in more detail below.

The sympathetic nervous system (SNS) and parasympathetic nervous system (PSNS) are two branches of ANS (Figure 3). It is best to associate the SNS with "fight or flight" and the PSNS with "rest and digest". The differences between these two branches should be discussed seperateley.

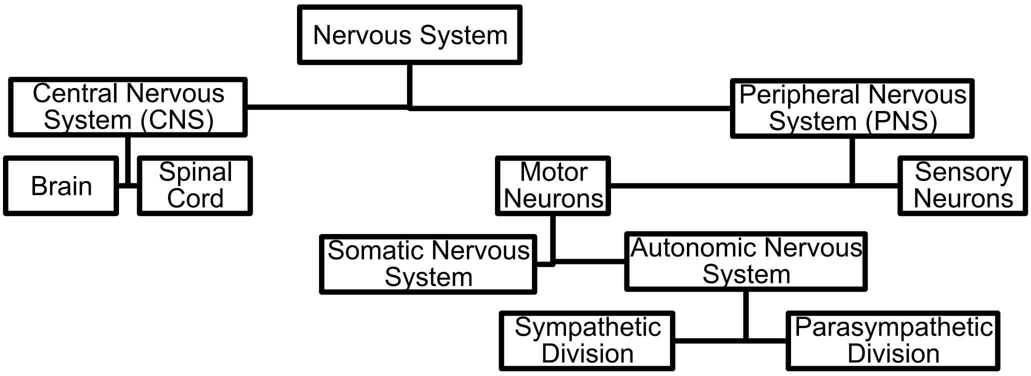


Figure 3: Division of the nervous system (Tortora & Derrickson, 2011).

The SNS "energizes" the body in stressful situations (e.g. in a competition) by stimulating the responses shown in Figure 4. An example of one of these stimulations is the secretion of epinephrine and norepinephrine. These hormones prepare the body for stress. It is also important that the SNS increases the contraction force, heart rate and blood pressure. These factors increase blood circulation in the muscles. When athletes feel they are getting an “adrenaline rush” before a competition, this sensation is probably due to the stimulation of the SNS and the body’s preparation for the competition. PSNS, on the other hand, does the opposite. It is responsible for lowering the heart rate and blood pressure in moments without stress. The main function of PSNS is to help ease recovery after a stressful situation (e.g. competition) by counteracting the impact of SNS (Tortora & Derrickson, 2011).

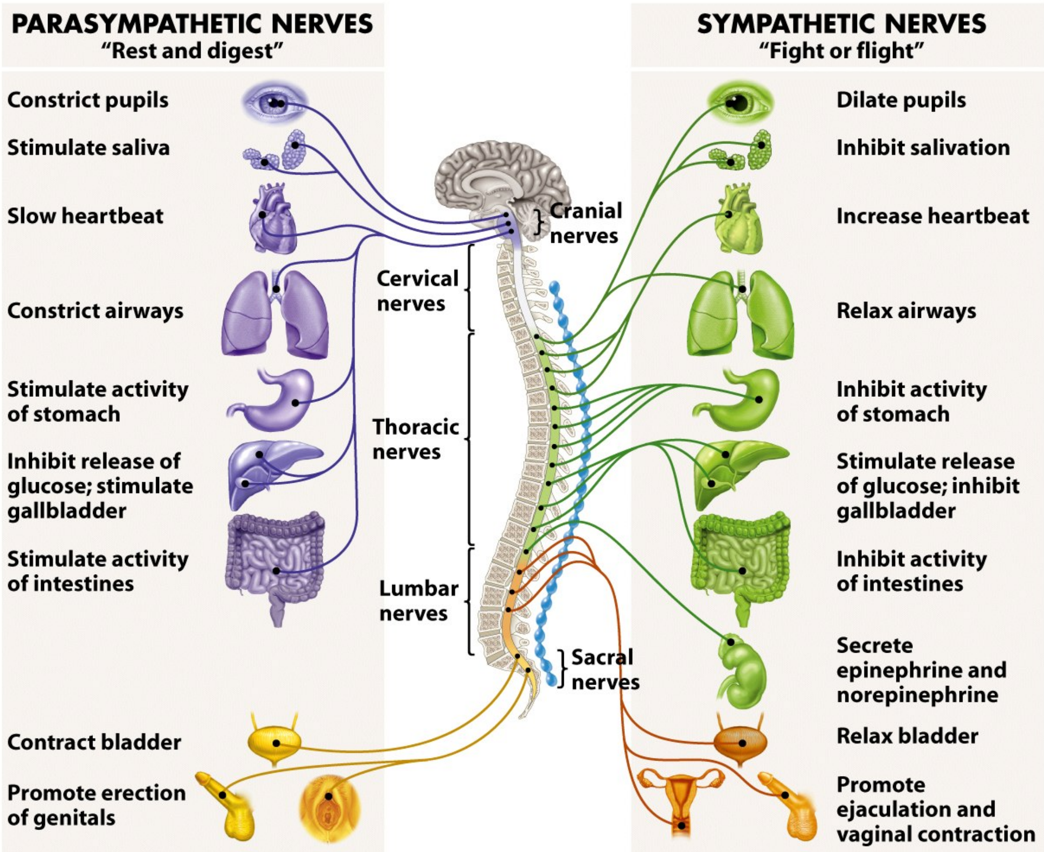


Figure 4: Effects of both the parasympathetic and the sympathetic on physical body (Freeman, 2005).

In simple terms, SNS and PSNS are mutually exclusive, as one increases heart rate and blood flow, while the other reduces the heart rate and peripheral blood flow. For performance and recovery both are essential. For the stress factors that occur during exercise, SNS stimulates the body, and for recovery and regeneration, PSNS has an important significance. It is assumed, that an imbalance between SNS and PSNS can lead to a reduction in athletic performance and, in extreme cases, overtraining (Kiviniemi, Hautala, Kinnunen, & Tulppo, 2007).

2.2 Historical outline of HRV

“If the heartbeat becomes as regular as the woodpecker's knocking or dripping rain on the roof, the patient will die within four days” (Mück, n.d.).

This excerpt from *The Knowledge of Pulse Diagnosis* by the Chinese physician Wang Shu-He is strongly reminiscent of the phenomenon called heart rate variability. *The Knowledge of Pulse Diagnosis* was the first work dedicated exclusively to pulse diagnostics, appearing around 280 AD and presuming 24 basic pulse types (Kaptchuk & Biller, 2010). Wang Shu-He apparently recognized more than 1700 years ago that a variable pulse rate is a sign of health as well as an indication of illness (ibid.).

Despite these early findings, heart rate variability made its entry into modern science relatively late, namely in the mid-1960s. As reported by Mück, the importance of HRV is first recognized in obstetrics, where it plays an important role in the form of cardiotocography to this day. Cardiotocography refers to a method for the simultaneous registration and recording of the heartbeat frequency of the unborn child and the labor of the expectant mother (Mück, n.d.)

Around the year 1975, interest in HRV, initially in the English-speaking world, increased more and more and continues to show an upward trend from year to year (ibid.). Figure 5 shows the number of publications in PubMed (medical publication database) in the respective year for the search term ‘heart rate variability’, whereby in 2012 more than 1000 papers on this topic or with this search term were published for the first time.

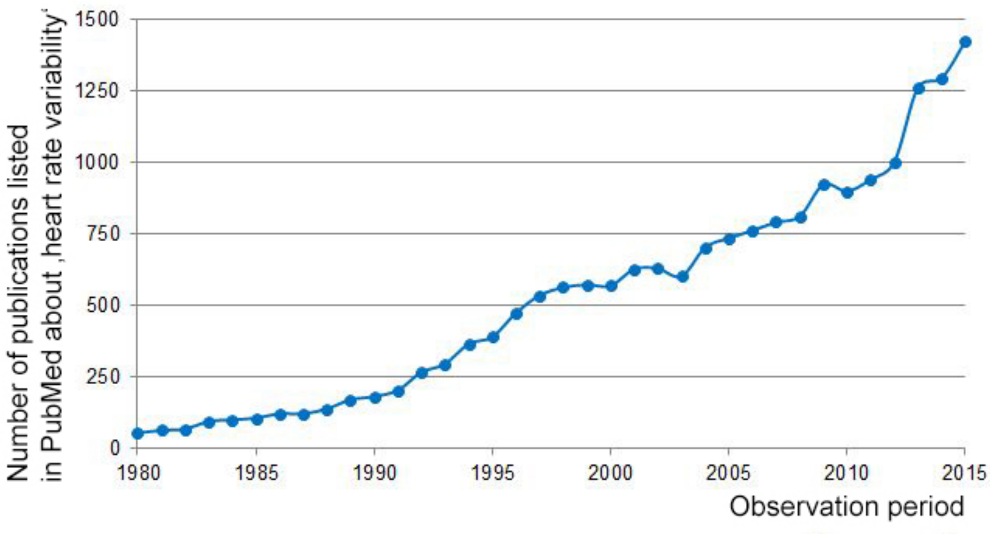


Figure 5: Publications listed in PubMed about ‘heart rate variability’ (Mück, n.d.).

2.3 Assignment of the HRV parameters

Due to the increasing importance of HRV as well as the complexity of various methods of measurement, guidelines for the measurement, interpretation and clinical application of HRV were published in 1996 by the ‘Task Force European Society of Cardiology and the North American Society for Pacing and Electrophysiology’ in the *European Heart Journal*. The main objective of these guidelines was to ensure adequate comparisons of further studies by standardizing the HRV parameters without slowing down the further development in the area of HRV (Task Force, 1996). The HRV can be described by linear methods such as time or frequency parameters, among others (Task Force, 1996).

2.3.1 Time domain analysis parameter

In the time domain analysis, either the heart rate at each point in the measurement or the interval length between successive normal RR complexes (NN = normal to normal) are determined (Task Force, 1996).

SDNN (ms) **(standard deviation of the NN interval)**	SDNN describes the standard deviation of all recorded NN intervals of a time range in milliseconds and thereby all periodic components of HRV, hence the total variability (representing sympathetic and parasympathetic) in a recording period (Hottenrott, 2006). $SDNN = \sqrt{\frac{1}{n-1}\sum_{i=1}^{N}(RR_i - \overline{RR})^2}$
RMSSD (ms) **(square root of the mean squared differences of successive NN intervals)**	RMSSD is another frequently-used parameter and calculates the square root of the mean squared differences of successive RR intervals (Hottenrott, 2002). $RMSSD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N-1}(RR_{i+1} - RR_i)^2}$
pNN50 (%) **(NN50)**	Percentage (number) of consecutive RR intervals that differ by more than 50 ms. $pNN50 = \frac{NN50}{N-1} \bullet 100\%$

RMSSD and pNN50 can be used for short-term measurements and mainly reflect parasympathetic activity (Task Force, 1996; Vanderlei et al., 2009).

Poincare plot

In addition to the statistical methods for determining the HRV parameters, there is the possibility of calculating the HRV parameters from the Poincare plot. This is a geometric two-dimensional graphical representation of a point cloud (Figure 6), which results from the application of two successive heartbeats (heart time intervals) Ri and Ri + 1. In healthy persons, recordings of the heartbeats at rest yield the image of an ellipse whose longer axis lies on the bisector of the coordinate system (Hottenrott, 2002). Points far beyond the point cloud indicate arrhythmias or measurement errors (artifacts) (ibid.).

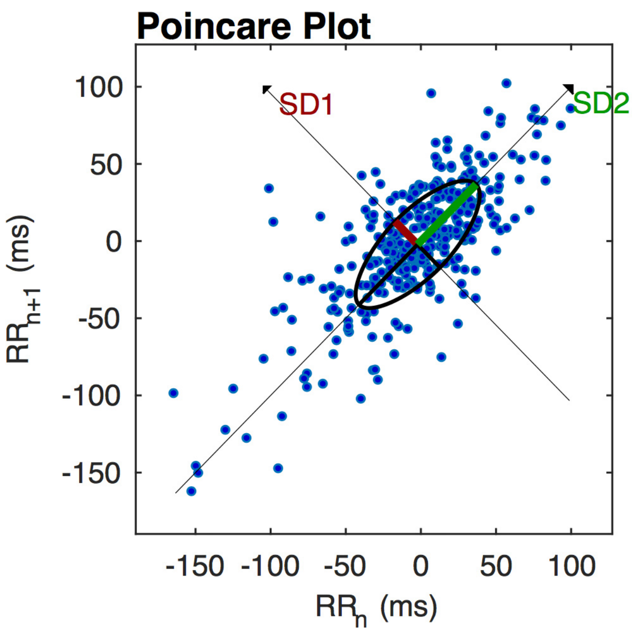


Figure 6: Poincare example scatter chart from the data (see appendix).

As described by Hottenrott (2002) using orthogonal regression analysis, longitudinal and transverse diameters are constructed into the 95% confidence ellipse and the standard deviation of the point distances to the longitudinal diameter (SD2 (SOL, SD-longitudinal, stda)) and transverse diameters (SD1 (SOQ, SD-transverse, stdb)) is calculated. The parameter SD1 (ms) provides information about spontaneous changes in the heart rate and is mainly influenced by the vagus nerve.

2.3.2 Parameters of the frequency analysis

In the HRV power density spectrum, which represents all acquired frequencies of a recording period, the functionality of cardiac control circuits becomes visible (Akselrod et al., 1981). In short-term measurements in a period of 2 to 5 minutes, a distinction is usually made between 2, in some literature references also 3, central peaks, namely very low frequency (VLF = very low frequency), low frequency (LF = low frequency) and high frequency (HF = high frequency) (Hottenrott, 2006; Task Force, 1996). See Table 1 for the description of the named parameters.

Table 1: Description of TP, VLF, HF, LF and LF/HF

TP (ms^2) **(Total Power)**	The TP represents the total frequency-level variability and includes all oscillations below 0.4 Hz (Task Force, 1996).
VLF (ms^2)	The VLF is assigned in the frequency range of 0.00 to 0.04 Hz (Hottenrott, 2002).
LF (ms^2)	The LF band includes all medium wave oscillations between approximately 6 and 25 s, which corresponds to a frequency range of 0.04 to 0.15 Hz (Task Force, 1996).
HF (ms^2)	All oscillations in the range between approximately 2.5 to 6 s, thus in the frequency range of 0.15 to 0.4 Hz, are assigned to the HF band (Hottenrott, 2006).
LF/HF (%)	Ratio between LF and HF band powers.

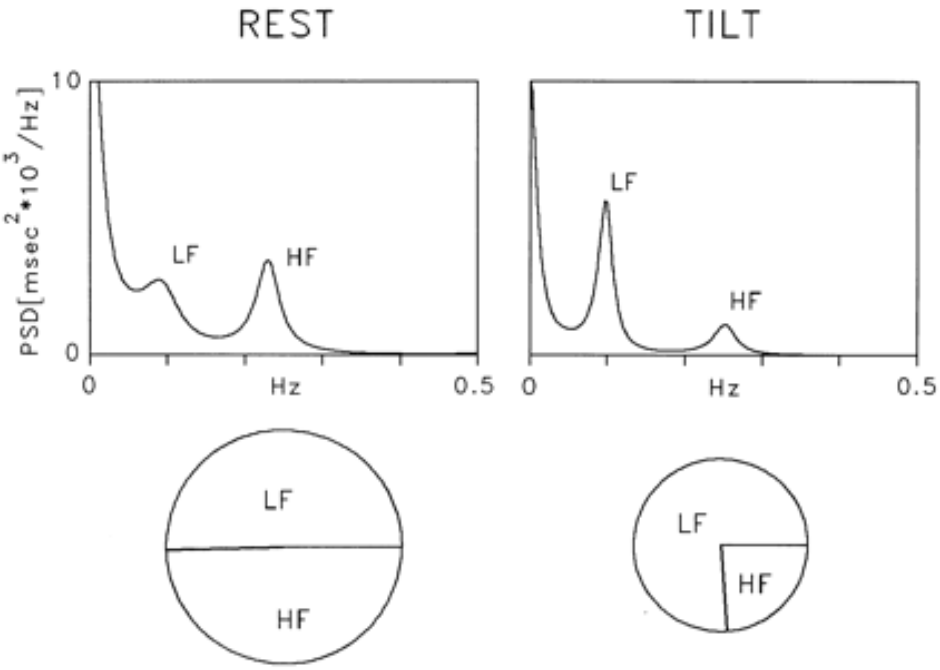


Figure 7: Spectral analysis of RR interval variability in a healthy subject at rest and during 90° head-up tilt (Task Force, 1996).

Figure 7 shows a spectral analysis of the variability of the RR interval in a healthy subject at rest and during a 90 degree head tilt.

> At rest, two major components of similar power are detectable at low and high frequencies. During tilt, the LF component becomes dominant, but as total variance is reduced, the absolute power of LF appears unchanged compared with rest. Normalization procedure leads to predominant LF and smaller HF components, which express the alteration of spectral components due to tilt. Pie charts show the relative distribution together with the absolute power of the two components represented by the area. During rest, the total variance of the spectrum was 1201 ms^2, and its VLF, LF, and HF components were 586 ms^2, 310 ms^2, and 302 ms^2, respectively. Expressed in normalized units (nu), the LF and HF were 48.95 and 47.78 nu, respectively. The LF/HF ratio was 1.02. During tilt, the total variance was 671 ms^2, and its VLF, LF, and HF components were 265 ms^2, 308 ms^2, and 95 ms^2, respectively. The LF and HF were 75.96 and 23.48 nu, respectively. The LF/HF ratio was 3.34. Thus, note that for instance, the absolute power of the LF component was slightly decreased during tilt while the normalized units of LF were substantially increased. (Task Force, 1996)

To get the spectral indices for a complete HRV power spectrum from a simple tachogram, the reuse of mathematical methods such as the Fast Fourier transformation is necessary (Kaptchuk & Biller, 2010).

2.4 Factors influencing heart rate variability

There are a number of factors that have an impact on heart rate variability. These influencing factors are described below.

Gender

The reported influence of gender on HRV differs in recent publications. A multitude of studies on body dysfunction in women show higher HRV parameters that are vagally modulated, possibly resulting in a lower cardiac risk in women (Antelmi et al., 2004). In contrast, higher values of the HRV parameters TP, LF, VLF and SDNN were found in healthy males compared to healthy females, suggesting that the known reduced cardiac risk in women may be partly due to decreased sympathetic activity (LF) (Ryan, Goldberger, Pincus, Mietus, & Lipsitz, 1994; Ramaekers, Ector, Aubert, Rubens, & Van de Werf, 1998).

Age

Hottenrott (2006) stated that people in old age deal with a decrease in HRV. This decreasing HRV can be used for the qualitative and sometimes also quantitative estimation of the age of the heart. Heart aging processes reduce the physiological reserve and increase the risk of heart disease, such as heart failure and coronary heart disease (Hottenrott, 2006).

Respiration

Breathing has a major impact on heart rate variability (Hirsch & Bishop, 1981; Hottenrott, 2002). During inhalation and exhalation, the pressure conditions in the chest change, whereby the blood circulation in the vascular system (especially in the pulmonary circulation) is influenced and there is a change in the pressure gradient. There is an increase in inhalation and a decrease in heart rate when exhaling. This influence of respiration on heart rate and HRV is called respiratory sinus arrhythmia (RSA) and has an effect on high-frequency parasympathetic activity (Task Force, 1996). Both the respiratory rate and the respiratory depth influence the regulation of the heart rate, with an expansion in the depth of the respiration increasing the RSA and the growth in the respiratory rate reducing RSA (König, Schumacher, Schmidt-Trucksäss, & Berg, 2003).

According to Murata (1992), specifically the respiration rate, respiratory depth, and scattering of the respiratory interval have an impact on heart rate variability. It has been shown that the number of peak and trough waves in the time series of the RR intervals is affected by the respiration rate. In addition, it was found that the measurements obtained by power spectral analysis of RR intervals were significantly affected by the respiratory rate. Measurements of heart rate variability tended to increase with deep breathing (Murata, 1992).

Stressors

Psychological and chemical stress as well as physical stress can also affect the HRV. Mental stressors such as work-related stress (Vandeput, Taelman J Spaepen, & Van Huffel, 2009), complex decisions (Dong, 2016), public tasks (Dong, 2016) and tests / examinations (Hjortskov et al., 2004) significantly lower the HRV. Another study reports that athletes who suffer from high stress achieve lower strength gains than athletes with lower stress levels (Bartholomew, Stults-Kolehmainen, Elrod, & Todd, 2008).

Myocardial infarction

In recent years and decades, it has become increasingly recognized that heart disease does not always have to come from the heart itself, and most often not only affect it. The isolated consideration broadened from the damaged organ to the investigation of the whole organism and the system reactions of cardiac illnesses. The analysis of the HRV was found to be a very good tool, which makes it possible to better understand cardiac diseases and detect them earlier (Hottenrott, 2004).

The HRV decreases after a myocardial infarction, which manifests itself in this case with an increased sympathetic and reduced parasympathetic activity and therfore a predominance of the sympathetic. This HRV decrease serves as a prognostic factor of lethality and arrhythmic complications. In particular, 24 hour SDNN values are used as limit values ("cut-offs"). Shorter recording intervals are possible, but should be avoided as the predictive value of decreased HRV increases with recording length. SDNN values below 100ms are considered to be moderately reduced, HRV lower than 50ms (Hottenrott, 2004) and SDNN values below 70ms indicate a times 3.2 increased risk of mortality (Hottenrott, 2006).

Diabetes mellitus

The elevated blood sugar level in diabetes mellitus patients / sufferers often damages the autonomous nervous system in addition to the heart, kidneys, blood vessels and the retina. Cardiac autonomic neuropathy, which affects approximately 40% of diabetics, results in CNS restriction of heart regulation and diminished pain on the heart. Even in patients without clinical signs of autonomic neuropathy, a reduction in the total strength of LF and HF was found under controlled conditions (Task Force, 1996). This explains the clinically mute heart attacks in diabetics. Hottenrott stated in 2004 and 2006, that autonomic dysfunction in diabetes mellitus patients manifests itself as a reduction in HRV and is of prognostic importance since diabetics with cardiac autonomic neuropathy have a twice as high mortality risk compared to those with diabetes.

Chronic heart failure

In order to identify those at risk of cardiac death, HRV analysis has been introduced in patients with chronic heart failure. One study in 2003, conducted by Musialik-Łydka et al., discovered that all measured HRV variables were lower in patients with chronic heart failure compared to healthy subjects.

Heart failure at high levels causes severe HRV restriction. SDNN values below 50ms are associated with a 50% annual mortality rate, while values above 100ms are associated with only 5.5%. As in patients with myocardial infarction, a predominance of the sympathetic nervous system can be seen even in those with chronic heart failure (Hottenrott, 2006).

Alcohol

The HRV is reduced depending on the alcohol level in the blood. For short-term measurements, the HF band appears to be most dependent on the level of alcohol. After alcohol poisoning, a significant increase in HRV was observed within 24 hours. An increased LF / HF ratio as an expression of sympathetic dominance persisted throughout the observation period (Süfke, Fiedler, Djonlagiç, & Kibbel, 2009). Decisive here seems to be the amount supplied. With a glass of alcohol (e.g., a glass of red wine or ethanol), no deterioration in HR and HRV could be detected compared to a drunk glass of water, whereas with 2 glasses of red wine/ethanol) the heart rate increased as well as LF by 28-34% and the LF / HF Ratio increased by 98-119% and total variability decreased by 28-33% and HF by 32-42% (Spaak et al., 2010).

Further factors

In addition to the factors already described, the HRV is subject to many other external influences. These include food intake, caffeine, nicotine and alcohol consumption and mental stress (Delaney & Brodie, 2000; Monforte et al., 1995; Task Force, 1996; Yeragani, Krishnan, Engels, & Gretebeck, 2005). Therefore, in advance of investigations, the external conditions must be standardized as far as possible and external disturbing factors minimized.

2.5 HRV during exercise

The measurement of HRV has only been relevant for sports since 1996 with the market launch of a mobile mini heart rate monitor (Polar Vantage), which was able to record the duration of each heartbeat with ECG accuracy (Hottenrott, 2002). Mobile beat-to-beat measurement analyzes the behavior of heart rate variability at rest and during physical activity. For athletes and coaches, this opens up new possibilities for controlling the stress of the training process.

The first extensive investigations accompanying the training process and examining the behavior of the HRV in competitive athletes in the endurance disciplines of triathlon, cycling and running were carried out by Neumann, Pfützner, & Berbalk (1998). The investigation results clarify:

- Individual HRV differences among endurance athletes, which require derivation of the individual reference ranges for sports-related movement diagnostics.
- Differences in HRV between male and female endurance athletes.
- Dynamics of HRV depending on the training load.
- An infection-related decrease in HRV.

In sports activities, it is essential to be informed objectively about the current state of health. Intensive training for onset or existing infections can worsen health and can even trigger complications (such as myocarditis). This is especially true for high cardiovascular activities (e.g. running). Athletes who regularly measure heart rate variability in training report improved individual tuning of each workout. The change between training and regeneration can be determined more accurately. This can lead to a constant performance progress, since overloads can be detected in good time and avoided (Hottenrott, 2002; Kiviniemi, Hautala, Kinnunen, & Tulppo, 2007).

In detail, during dynamic exercise, the heart rate increases due to an increase in sympathetic and a decrease in parasympathetic activity (Tulppo, Makikallio, Takala, Seppanen, & Huikuri, 1996). The relationship between the two parts of the autonomic nervous system depends on the intensity of the stress. At the beginning of exercise, the heart rate increases mainly due to a decrease in vagal activity. Only at higher stress levels is the increase in heart rate modulated above all by the increasing sympathetic activity. Thus, the uniformity in the beat-to-beat sequence during intense exercise can be considered as the result of a strong presence of the sympathetic (Berg & Latin, 2008; Bernardi & Piepoli, 2001; Maciel, Gallo, Marin Neto, Lima Filho, & Martins, 1986).

2.5.1 Monitoring recovery status and overtraining with HRV

As mentioned before the HRV reflects the ANS function and with that the level of stress. In the sporting world, the HRV is therefore often used to determine or monitor the following three areas in athletes (Aubert, Seps, & Beckers, 2003):

- Determine optimal training times
- Monitor recovery status
- Monitor possible overtraining

Recovery status

In summary, an increase in HRV signifies a positive recovery status, while a reduction in HRV can reflect a negative recovery status. Several research studies have shown that after intensive training sessions the HRV decreases. One study (Chen et al., 2011) shows that the HRV decreased in the post-workout 24 hours after an intensive strength training. After 72 hours of recovery, the performance of HRV and weight lifting returned to pre-workout levels. This clearly indicates a relationship between HRV and recovery.

A second study, also found a relationship between training load and HRV. In this case, before and during rowing at world championships in national rowing athletes (Iellamo, Pigozzi, Spataro, Lucini, & Pagani, 2004). The HRV decreased significantly when the athletes were exposed to high training loads before the rowing competition. After the training load was significantly reduced during the competition, their HRV increased and returned to the previous level.

Another study (Pichot et al., 2002) monitored athletes over several months. Results show that HRV increased during an intense training period, then stagnated and declined during a period of overload. After that, the athletes went into a recovery period of two weeks. During this time, the HRV recovered and even increased. These studies have shown that intensive training programs might have a significant impact on the potential for improvement of HRV.

Performance

When HRV and its impact on performance are discussed in literature, the concept of HRV-guided training plans is usually analyzed in comparison to pre-planned training plans. For example, Kiviniemi et al., 2007 and Vesterinen et al., 2016 have examined HRV-guided training. In these studies, daily monitoring of HRV was performed. The result of the daily HRV monitoring defined the intensity of the daily endurance sessions. Previously, the result was compared with an individually scaled reference or control value. Basically, the idea of HRV-guided training is to decrease the training stimulus as the HRV decreases, and to maintain the training stimulus if the HRV stays the same or increases.

In 2007, a study compared the impact of HRV-guided training plans to pre-planned plans. Thirty healthy recreational male runners were randomized into a predefined training group, an HRV-guided training group and a control group. In a four-week training period, the subjects participated in 40-minute running sessions on a low or high intensity. It was found that the HRV-guided training group improved their maximum running speed to a higher level than the pre-planned group (Kiviniemi et al., 2007). The study thus suggests that cardiorespiratory fitness can be effectively improved during exercise by using daily vagally-mediated HRV for physical prescription. Measurements of HRV can help determine the timing of intense workouts based on the status of autonomic regulation. In order to achieve a favorable response to endurance training with reduced, vagally-mediated, beat-to-beat HRV, a decrease in exercise stimulus may be beneficial. To support the previous findings, a more recent study found supportive evidence that HRV-guided training plans for men have more effect than pre-planned plans (Kiviniemi et al., 2010).

It should be noted that, so far there is no research to date, which argues that HRV-guided training is more effective for performance development than pre-planned training sessions.

Overtraining

Increasing the intensity and volume of training is usually done by athletes to improve physical performance. However, disrupting the balance between proper training stress and adequate recovery can result in an unusual training response and may result in functional overreaching. Intensified training can then lead to performance losses. However, if adequate recovery periods are provided, a "supercompensation" effect may occur in which the athlete develops improved performance compared to the baseline values. If this intensified training continues, athletes may develop into a state of extreme overreaching or non-functional overreaching resulting in stagnation or a performance drop of several weeks or months (Aubry et al., 2015).

Over time, overreaching can result in overtraining (Fry & Kraemer, 1997, Halson & Jeukendrup, 2004). Overtraining is divided into different degrees, these vary from study to study. Several experts consider overtraining a continuum, while others question the connection between overreaching and overtraining (Halson & Jeukendrup, 2004). The most widely accepted theory in the literature is from the European School of Sports Medicine (Kreher & Schwartz, 2012). Table 2 shows the terminology from position statement on overtraining stated by European College of Sport Science.

Table 2: Terminology from position statement on overtraining

Term	Synonym	Definition	Performance Decrement	Outcome
Functional overreaching (FO)	Short-term overreaching	Increased training leading to a temporary (day to weeks) performance decrement and with improved performance after rest	Days to weeks	Positive (super-compensation)
Nonfunctional overreaching (NFO)	Long-term overreaching	Intense training leading to a longer performance decrement (weeks to months) but with full recovery after rest. Accompanied by increased psychologic and/or neuroendocrinologic symptoms	Weeks to months	Negative due to symptoms and loss of training time

Overtraining syndrome (OTS)		Consistent with extreme nonfunctional overreaching but with a) longer performance decrement (> 2 months) b) more severe symptomatology and maladapted physiology (psychologic, neurologic, endocrinologic, immunologic systems) c) an additional stressor d) not explained by other disease	Months	Negative due to symptoms and possible end to athletic career

Note: By Europea College of Sport Science (Meeusen et al., 2006).

To best distinguish the main difference at one glance between overreaching and overtraininig this can be divided into two stages. The first stage is "Nonfunctional Overreaching (NFO)": This level of exercise overload can be restored within weeks to months. A complete recovery is possible. The second stage is "Overtraining Syndrome (OTS)". If NFO is ignored, it may become OTS, resulting in worse symptoms and a performance drop of more than 2 months. It may take months or years for the problem to recover, if any recovery is achieved (Bernardi & Piepoli, 2001).

In the autonomic nervous system the sympathetic branch increases its activity when the body registers physical, mental, chemical or cumulative stress. This releases adrenaline and cortisol, thereby releasing more glucose in the liver. In addition, the activity of the parasympathetic branch is suppressed. If these only lasts for a few hours, this is something the body should process well. Overtraining, however, causes the ANS to behave in this way for extended periods of time, which the body can no longer endure without consequences (Bernardi & Piepoli, 2001).

HRV is a good indication of an athlete’s current level of cumulative stress as it is regulated by ANS activity. The more difference there is in the gaps between the heartbeats, the healthier a heart is. A healthy heart has a high variance and can react faster to physical demands than a tired, stressed organ. As cumulative stress increases, the heartbeat rhythm becomes more regular. If the HRV is reduced over a period of time, this is a sure sign of being on the verge of overtraining. A person might become ill, or at least be so fatigued that his or her ability to respond to exercise is compromised (Fry & Kraemer, 1997).

The results of one study showed that cardiac autonomic modulation in overtrained athletes occurs during sleep at the level of the control athletes and that the parasympathetic cardiac modulation is slightly reduced after waking up (Hynynen, Uusitalo, Konttinen, & Rusko, 2006). This research indicates that the negative effects of overtraining on the automatic system are reversible with sufficient rest. Another investigation of HRV in middle-distance runners discovered that HRV is a better indicator than resting heart rate to assess cumulative fatigue (Pichot et al., 2000). In a four year study of elite nordic skiers the findings where that HRV was significantly lower in fatigued athletes (Schmitt et al., 2013).

To sum it all up, in any case the goal of a training plan should be to prevent overtraining. It can take months to treat overtraining. Several studies have shown that measuring HRV can be helpful in avoiding over-training. Keeping a close eye on HRV provides useful and practical information about the risk of overtraining and the willingness to accept the burden.

2.6 Aerobic/anaerobic exercise

An optimum level of performance depends on the development of physiological responses to meet the challenges of competitive situations, with the exception of technique, skills and tactics. Therefore, evaluating and monitoring a training schedule effectively is the main purpose of physiological research. For high performance endurance training, the most important physiological factor is to possess a high aerobic capacity (Ghosh, 2004).

The threshold point at which an athlete passes from the aerobic to the anaerobic training area is mainly important for high-performance endurance athletes (e.g. triathletes, cyclists or runners) for training control. There are several ways to determine this threshold; for instance, you can repeatedly take blood from the athlete during exercise, and then use it to determine the lactate value and thereby determine the threshold. One of the most prominent tests is the Conconi test, which was developed by Conconi in 1982. Over 200 runners were tested, and Conconi's team discovered that the heart rate does not increase linearly with increasing power from a certain point. This point is called the heart rate deflection point, which is determined with a so-called deflection curve. The exact test procedure according to Conconi can be found in Chapter 3.2.2 Treadmill ergometric test (Conconi, Ferrari, Ziglio, Droghetti, & Codeca, 1982).

2.7 Research questions

In sports medicine and sports science, the development of non-invasive methods for characterizing neurovegetative states of humans is becoming increasingly important. In this context, heart rate variability has also come to the fore in recent decades in these fields as well. Particularly in the area of exercise training control, HRV could be an important criterion for assessing the regeneration processes of athletes. HRV has recently been the subject of scientific research during exercise. Through the analysis of the heartbeat dynamics during increasing stress, statements about the vegetative control of the heart activity can be made. There are also changes in HRV during exercise that is related to metabolic and respiratory parameters.

Therefore, the influences of HRV have already been tested in several studies during exercise training, but there are not yet enough studies regarding the reliability of the HRV measuring methods (Anosov et al., 2000; Cottin et al., 2006; Tulppo, Mäkikallio, Seppänen, Laukkanen, & Huikuri, 1998).

Based on these results, the following questions are addressed in the present study:

Research Question 1: How reliable is heart rate variability during a “change of position test” and treadmill ergometric exercise in performance-oriented subjects and a peer group?

Research Question 2: At the anaerobic threshold, can a difference in heart rate variability be found among trained and untrained subjects?

3 Requirements/Methodology

This chapter covers all the requirements and methods used in this pilot study.

3.1 Participants

Ten male volunteers, age approximately 30+ (five years deviation upwards), participated in this pilot study. Five of these subjects are active performance-oriented athletes who performed intensive and regular endurance training sessions (ø more than 6 hours per week), such as triathlon, running and cycling, in the last 3 months. The subjects in the control goup exercise less than 5 hours per week. These are, for example, recreational athletes who engage in sports activities solely for physical fitness and the balance of everyday life. The demographic data of the subjects are shown Table 3.

Table 3: Characterization of the examined participants (n = 10) according to anthropometric data

Characteristic value	total (n = 10)	trained (n = 5)	untrained (n = 5)
Age (years)	32.6 ± 1.9 (30.0; 35.0)	31.8 ± 1.2 (30.0; 33.0)	33.4 ± 2.06 (30.0; 35.0)
Height (cm)	179.2 ± 6.2 (170.0; 191.0)	179 ± 4.8 (174.0; 188.0)	179.4 ± 7.4 (170.0; 191.0)
Weight (kg)	77.1 ± 10.3 (72.0; 93.0)	70.4 ± 7.8 (58.0; 79.0)	83.8 ± 7.9 (72.0; 93.0)

(MW ± sd, Min; Max)

The inclusion criteria included men who were between 30 and 35 years old. In addition, subjects were sought, as mentioned above, which performed regular endurance sessions in the amount of more than 6 hours per week and also those who fell below this weekly number of hours. In order to recruite active performance-oriented athletes, requests were placed in triathlon clubs.

To assure a healthy state of the subjects and their ability to perform the given tests, the following exclusion criteria applied:

- Medical prescription, which recommends exercise and sports only under medical supervision
- Medication intake against high blood pressure or heart problems
- Diseases such as: diabetes, asthma or chronic bronchitis
- Cigarette consumption in the last 4 weeks
- Illness or fever within the last 3 weeks

3.2 Procedure

The study participants were fully informed about the purpose and procedure of the study and subsequently signed a consent form. In addition, a standardized questionnaire, the ‘Physical Activity Readiness Questionnaire (PAR-Q)’ from the *ACSM's Guidelines for Exercise Testing and Prescription* (American College of Sports Medicine, Riebe, Ehrman, Liguori, & Magal, 2018), was filled out by the participants and gathered information about their current health status.

The participants also received an information letter, which included a brief description of the test procedure and specifications for the most standardized test procedure possible. The participants were required to have their last meal up to 2 hours before the examination time. Furthermore, the participants were instructed to refrain from any caffeine or alcohol consumption as well as any physical activity on the day of the test.

In order to answer the research questions, two tests were conducted with the participants. As a first test, the "change of position" test was performed by each subject. This test was chosen in this pilot study, in order to give the subjects the opportunity to calm down after the day-to-day stress and because this test generally record the vegetative recovery process. In addition, this test has already been investigated in many studies to be a usefool and reliable tool to measure HRV (Chen et al., 2011; Hynynen et al., 2006; Iellamo et al., 2004; Kiviniemi et al., 2007) and is recommended by renowned companies such as Polar for daily monitoring of the balance between training and recovery. More in-depth information about the change of position test can be found in chapter 3.2.1 “Change of position” test.

In order to answer the second research question ("At the anaerobic threshold, can a difference in heart rate variability be found among trained and untrained subjects?"), a second test was carried out by the subjects: The treadmill ergometric test according to the Conconi test scheme. This test was necessary to find the anaerobic threshold of the individual subjects. In addition, the reliability of HRV was examined with this test. In chapter 3.2.2 the whole procedure about this test is explained.

This study was authorized by the ethics committee of the Federal State Lower Austria.

3.2.1 "Change of position" test

A common short-term study method for recording the vegetative situation is the "change of position test". This test consists of a 15-minute measurement with a sequence of 5 minutes lying, 5 minutes standing and 5 minutes lying again. The change from a lying to a standing posture makes it possible to assess the interaction between the sympathetic and the parasympathetic, as the change from the lying to the vertical position is accompanied by a strong sympathetic stimulus (König et al., 2003). Due to the changed hemodynamics, there is a redistribution of the blood, a regulation of the vessel wall tension and an increase of the heart activity in this phase (ibid.). The parasympatheticus is correspondingly strongly down regulated in this phase (ibid.). In the lying phases, however, the parasympatheticus should outweigh its sympathetic presence (ibid.).

Each subject completed the "change of position test" immediately before the treadmill ergometric test in order to record the vegetative recovery process. To make the test consistent, simple small talk was conducted with the subjects throughout the procedure. During the test period of 15 minutes, the heart rate and RR intervals used to describe the HRV were recorded continuously using the Polar Watch RS800CX (see 3.2.3 Hard- and Software description).

3.2.2 Treadmill ergometric test

The subjects completed a standardized treadmill ergometric exercise examination according to the Conconi test scheme to find out the anaerobic threshold.

The participants started with a 5-minute warm-up on the treadmill, where they chose a running speed between 6 and 7 km/h in which they felt comfortable.

After the 5-minute warm-up, the running speed was increased by 0.5 km/h every 200 meters. The end of the test was different for each runner. If the preset tempo could not longer be maintained over a 200m section, the treadmill stopped slowly. The runner then left the treadmill and the heart rate was recorded and stored for about 1 to 2 minutes. Depending on the level of performance, the run took between approximately. 12 to 32 minutes.

During the treadmill ergometric test, heart rate variability and heart rate was continuously measured and automatically recorded.

Figure 8 shows an example of the whole test procedure, beginning with the 15-minute change of position test and followed by the treadmill ergometric exercise based on the Conconi test scheme.

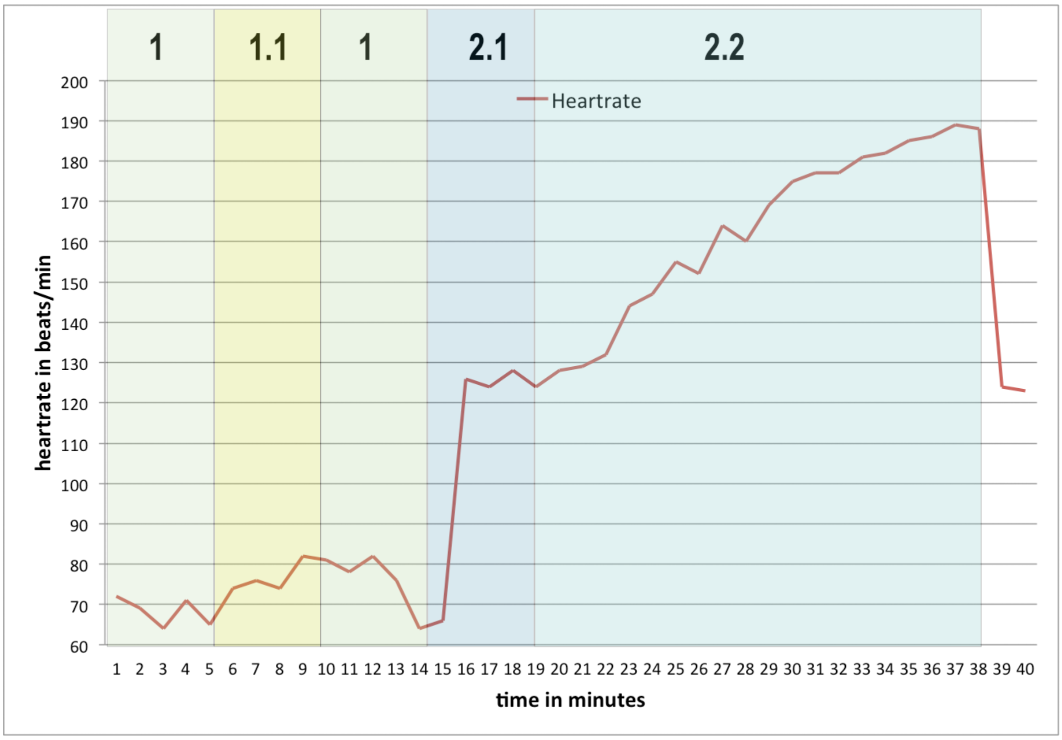


Figure 8: Overview of the heart rate measurement process: (1): 5 minutes lying (1.1): 5 minutes standing (2.1): 5 minutes warm-up (2.2): load phase, duration is individual for each subject and is depending on the maximum load.

3.2.3 Hard- and Software description

To perform the various tests with the subjects, a treadmill, a sports watch and a chest strap to measure the pulse accurately were required.

Hardware

The measurements for this study were performed on a treadmill (ergo_run premium8 (daum electronic GmbH)).

For this study, the polar watch, Polar RS800CX (Company Polar® Elektro, Finnland), was chosen since this watch can accurately measure heart rate variability. This watch has already been recently tested in terms of its validity and partly compared with the gold standard ECG in many studies (Essner et al., 2015; Essner, Sjöström, Ahlgren, & Lindmark, 2013; Hernando, Garatachea, Almeida, Casajús, & Bailón, 2016; Schega et al., 2010)

Based on the ECG principle, the watch measures the electrical potentials generated during each cardiac action in the form of the peaks of the QRS chamber complexes (R waves). From this, the RR interval (ms) and the heart rate (bpm) can be derived. The electrical pulses are recorded by electrodes in a chest strap and sent by default to the computer chip of the external receiver in wristwatch format. The storage of the HRV data was carried out in "beat-to-beat" intervals of the RR recording mode. In addition, the transmitter was previously provided with electrode gel to optimize the contact between the skin and the transmitter and to reduce the number of artifacts. It was also ensured that one and the same person carried out the investigation as well as the evaluation.

Software

The software "Kubios HRV Standard" (Biosignal Analysis and Medical Imaging Group at the Department of Applied Physics, University of Kuopio, Kuopio, Finland) was used to process the extracted raw data.

3.2.4 Test reliability

In order to check the reliability of heart rate variability, the same test was repeated after a one-week interval under the same conditions and with the same subjects.

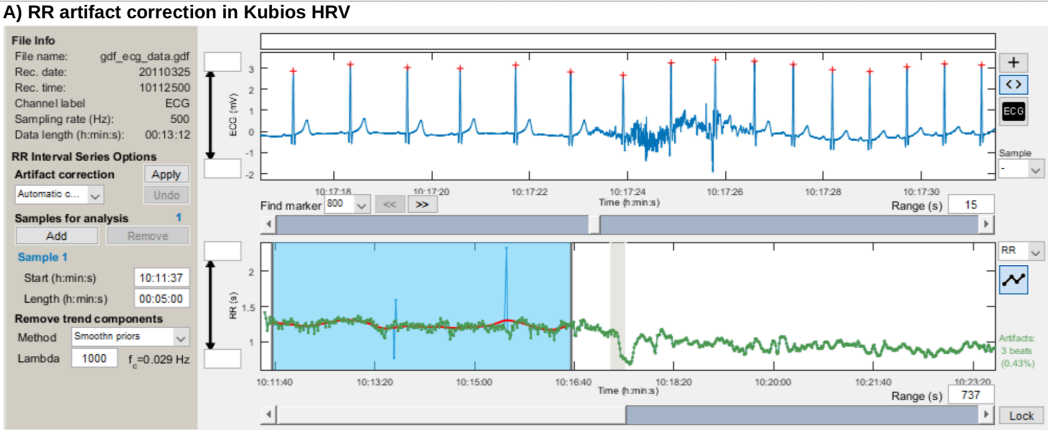
3.3 Data processing

This chapter discusses how the data of the performed measurements were processed.

3.3.1 Artifact elimination

Before the data could be statistically evaluated, the files had to be examined for artifacts. Artifacts can be caused by movements, electrode defects or strong baseline fluctuations thus resulting in corrupted RR interval series. The software Kubios has two features that can correct artifacts: “Automatic correction“ (availble only in Premium Version) and „Threshold correction“. Figure 9 shows an example of the automatic correction with Kubios Software.

A) RR artifact correction in Kubios HRV



B) Without artifact correction

Time-Domain Results

Variable	Value	Units
Mean RR*	1228.9	ms
STD RR (SDNN)	93.462	ms
Mean HR*	49.099	beats/min
STD HR	3.4995	beats/min
Min HR	44.851	beats/min
Max HR	55.089	beats/min
RMSSD	136.38	ms
NNxx	108	
pNNxx	44.444	%
HRV triangular index	9.7600	
TINN	989.00	ms

C) Artifacts corrected

Time-Domain Results

Variable	Value	Units
Mean RR*	1225.0	ms
STD RR (SDNN)	49.300	ms
Mean HR*	49.114	beats/min
STD HR	2.4390	beats/min
Min HR	45.358	beats/min
Max HR	54.298	beats/min
RMSSD	58.785	ms
NNxx	104	
pNNxx	42.798	%
HRV triangular index	11.619	
TINN	231.00	ms

Figure 9: RR interval artifact correction in Kubios Software. A) The artifact-corrected series is displayed on the RR interval series; the summary of the corrected beats in the recording is on the right side of the RR data axis. B) Time-domain analysis results before artifact correction. C) Time-domain analysis results after the artifacts habe been corrected. (Tarvainen, Lipponen, Niskanen, & Ranta-aho, 2017)

Since only the free version was available for this study, “threshold correction”, was used to correct the artifacts. The “threshold correction” simply compares each beat interval against a local mean RR and identifies the beat as an artifact if it exceeds the specified threshold. The normal variability in RR intervals may be quite different between individuals and therefore a fixed threshold could overcorrect the RR data. Hence, the correction level was adjusted individually (for each subject) as follows: When artifacts were present, the lowest possible correction level was manually selected which identifies the artifacts but does not identify too many normal RR intervals as artifacts.

Smoothness priors detrending method

An interfering low frequency baseline trend component may sometimes be included in the RR interval time series. Detrending options can be used to remove these types of trend components. One of the detrending options that Kubios software offers is the smoothness priors method. The smoothness of the removed trend can be adjusted by editing the lambda value (the larger the value of lambda, the smoother the remote trend). The smoothness priors method is essentially a time-varying high pass filter and its cut-off frequency can be adjusted with the Lambda parameter (Tarvainen, Ranta-aho, & Karjalainen, 2002). For the data evaluation in this study, the lambda value was set to 500 to remove disruptive low-frequency baseline trend components. Figure 10 shows an example of the recording of a subject while its first lying phase during the change of positon test. Left side shows the data before the smoothness priors method was set and on the right the lambda value was set to 500.

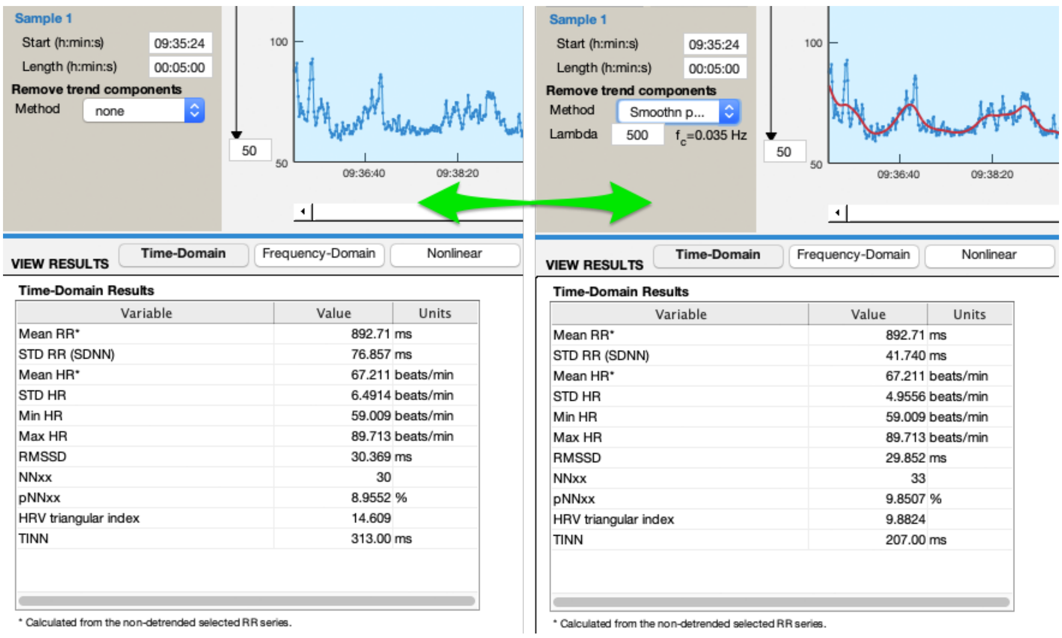
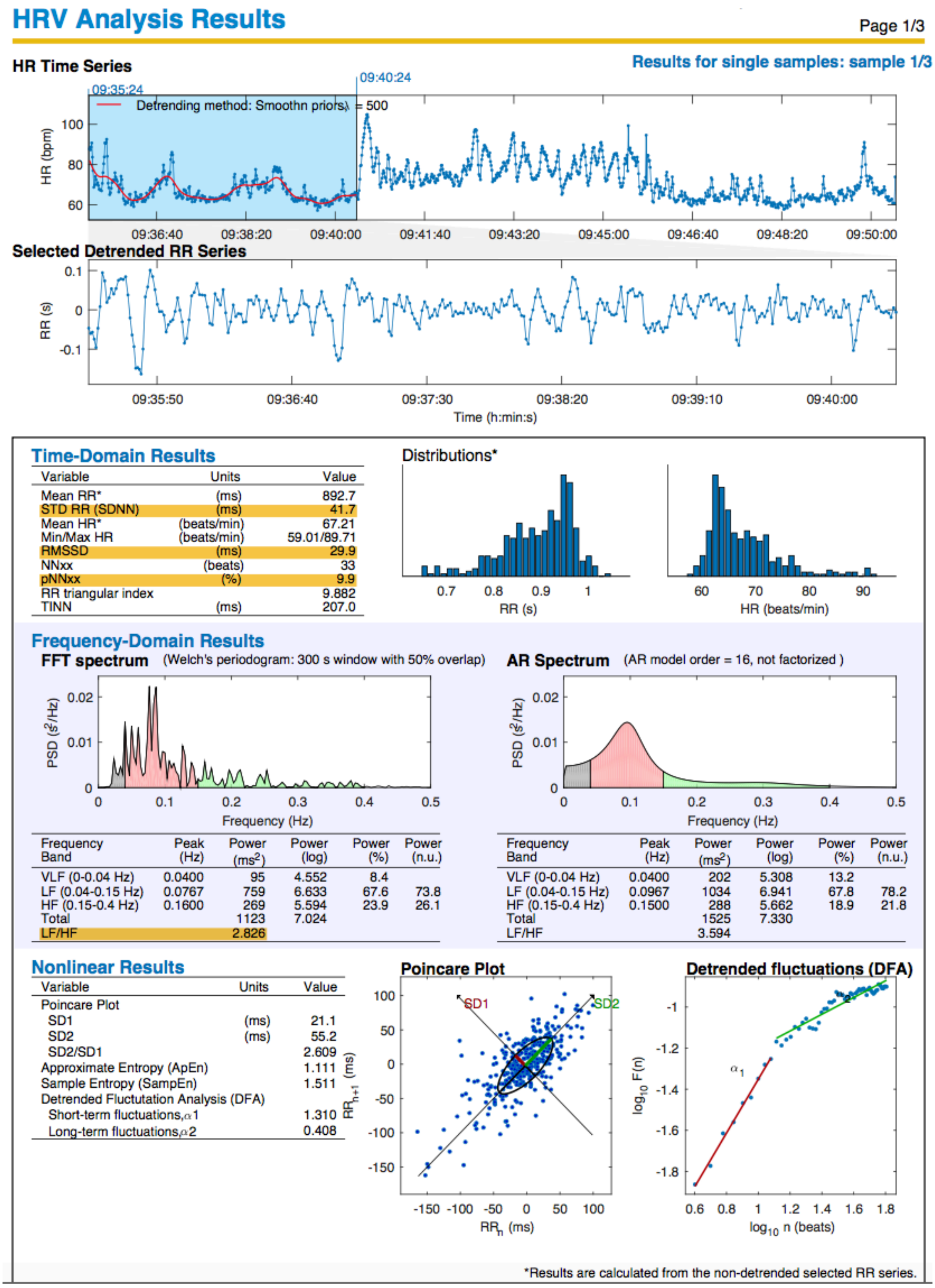


Figure 10: The estimated cutoff frequency for the specified lambda value (500) is displayed next to the Lambda edit field. The trend to be removed from the RR interval data is displayed as a red line above the analyzed RR data sample.

3.3.2 Processing HRV data from the “change of position test”

The 15-minute “change of position test” served as preparation for subjects before the Conconi Test and to evaluate the reliability of HRV.

In the change of position test, the HRV data were recorded over the entire test period of 15 minutes in the present study and the 5-minute intervals for the position change were evaluated separately (see Figure 11). The parameters RMSSD (ms), pNN50 (%) and the LF/HF ratio (%) were used to assess the vagal activity before the exercise situation. RMSSD (ms) provides information on the parasympathetic influence on cardiac activity and characterizes short-term changes in RR intervals. PNN50 (%) describes the percentage of consecutive RR intervals that differ by more than 50 ms. The parameter LF/HF ratio (%) from the frequency analysis can be used to estimate the vagal (stress-related) and sympathetic (stress-related) influence on cardiac work (49).



Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	892.7
STD RR (SDNN)	(ms)	41.7
Mean HR*	(beats/min)	67.21
Min/Max HR	(beats/min)	59.01/89.71
RMSSD	(ms)	29.9
NNxx	(beats)	33
pNNxx	(%)	9.9
RR triangular index		9.882
TINN	(ms)	207.0

Frequency-Domain Results

FFT spectrum

Frequency Band	Peak (Hz)	Power (ms^2)	Power (log)	Power (%)	Power (n.u.)
VLF (0-0.04 Hz)	0.0400	95	4.552	8.4	
LF (0.04-0.15 Hz)	0.0767	759	6.633	67.6	73.8
HF (0.15-0.4 Hz)	0.1600	269	5.594	23.9	26.1
Total		1123	7.024		
LF/HF		2.826			

AR Spectrum

Frequency Band	Peak (Hz)	Power (ms^2)	Power (log)	Power (%)	Power (n.u.)
VLF (0-0.04 Hz)	0.0400	202	5.308	13.2	
LF (0.04-0.15 Hz)	0.0967	1034	6.941	67.8	78.2
HF (0.15-0.4 Hz)	0.1500	288	5.662	18.9	21.8
Total		1525	7.330		
LF/HF		3.594			

Nonlinear Results

Variable	Units	Value
Poincare Plot		
SD1	(ms)	21.1
SD2	(ms)	55.2
SD2/SD1		2.609
Approximate Entropy (ApEn)		1.111
Sample Entropy (SampEn)		1.511
Detrended Fluctutation Analysis (DFA)		
Short-term fluctuations, α1		1.310
Long-term fluctuations, α2		0.408

Figure 11: This example of one subject in this study presents the HRV analysis results of the first 5-minute interval from the 15-minute change of position test made with the software Kubios.

3.3.3 Processing HRV data from the anaerobic threshold

The deflexion point and the anaerobic threshold of each subject were determined visually by an expert. This deflexion point and anaerobic threshold was only determined in one of the two tests (first Conconi test and Conconi retest). The reason for this is that not every subject reached the anaerobic threshold in both Conconi tests.

Figure 12 shows an example of the Conconi test and its determined anaerobic threshold from one of the subjects in this study.

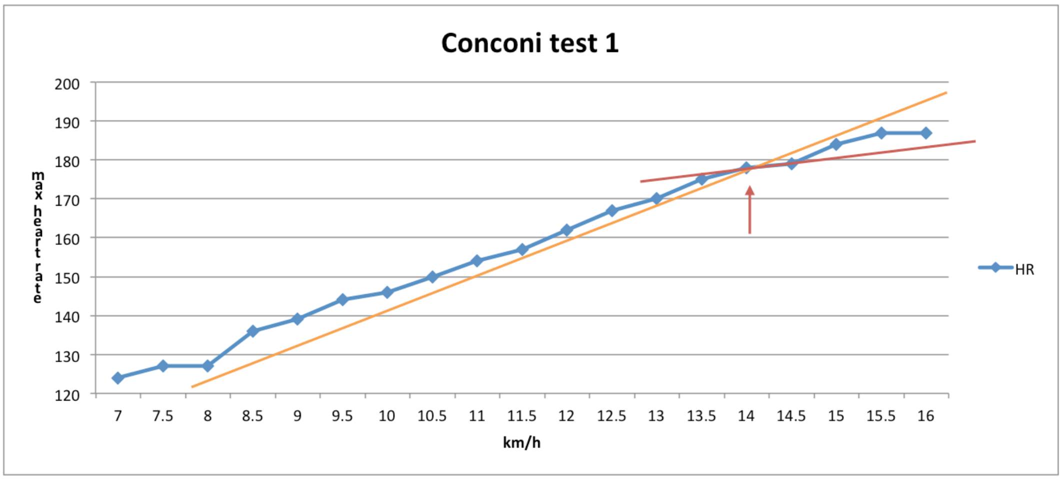


Figure 12: As visually determined by an expert, the deflexion point in this diagram is at a speed of 14 km/h at 00:23:02, therefore the anaerobic threshold was determined to be at a pulse value of 180 bpm. HR = heart rate.

The duration of the Conconi test was different for each subject. Depending on the endurance and ability of the subject, the duration of the Conconi test ranged between 10 and 30 minutes. For each subject, the evaluated range in this study of the Conconi test was one minute of the total elapsed time (this includes the range of the deflexion point and the anaerobic threshold). Afterwards, the values of the trained group were compared with those of the untrained group.

Figure 13 shows an example graph from one subject and the selected minute where the deflexion point and thus the anaerobic threshold were determined.

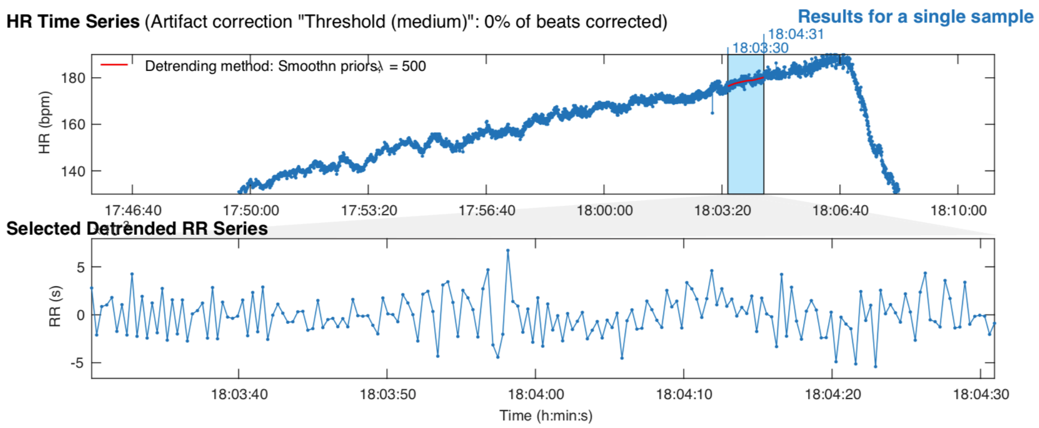


Figure 13: The total time of this example was about 25 minutes. The graph "HR Time Series" shows the selected Minute at 18:03:30. The graph below shows the selected detrended RR Series from this minute.

In addition, the reliability of the HRV was also compared at the anaerobic threshold between the first and second Conconi test. In order to check the reliability of the HRV at the anaerobic threshold in the two Conconi tests, the second test evaluated the same pulse range as the previously set anaerobic threshold. The evaluation range was also one minute.

The parameters RMSSD (ms), TP (ms^2), LF (ms^2), HF (ms^2), mean HR (beats/min) and SD1 were used to assess the vagal activity at the anaerobic threshold. SD1 reflects, as well as RMSSD, parasympathetic heart activity.

3.4 Statistical method

The statistical evaluation of this study was done by preparing the collected data in Excel and the following calculation was made with the program Past 3.20 (by Øyvind Hammer, Oslo) for Mac.

Kendall's tau coefficient

Kendall's tau coefficient was calculated to measure the strength of the statistical relationship of HRV values to each other in order to find out if the HRV is reliable or not. The Kendall rank correlation coefficient is helpful if the data are not normally distributed, the scales have unequal divisions, or if the sample sizes are very small. Since the sample sizes was n <10 in this study, this test was selected.

Kendall's tau is defined as:

$$\tau = \frac{concordant - discordant}{\sqrt{concordant + discordant + extray}\sqrt{concordant + discordant + extrax}}$$

All possible N (N-1) / 2 pairs of bivariate data points are considered. If two pairs in x have the same direction as in y (x and y decrease or both increase), they are called concordant. If not, they do not agree (= they are discordant). A tie in the x's is called an extrax, and a tie in the y's is called an extray. Pairs with bindings in both variables are discarded. The number of pairs in the four categories is counted (Hammer, 2018).

Effect size r

To assess the significance of a result, effect sizes are calculated. In order to determine how strong the correlation is, the following classification of Cohen (1992) was used:

r = 0.1 equals a weak effect
r = 0.3 equals a mean effect
r = 0.5 equals a strong effect

Mann-Whitney U test

The Mann-Whitney U test - also known as the "Wilcoxon rank-sum test" - for independent samples tests whether the central tendencies of two independent samples are different. The Mann-Whitney U test is used if the requirements for an independent sample t-test are not met. Since the groups with n <10 were too small to perform an independent t-test, this test was used in this study. The Mann-Whitney U test was calculated to analyze any difference in HRV in the anaerobic threshold between the trained and the untrained groups.

The Mann-Whitney U test is based on the idea of mapping the data. This means that it is not calculated with the measured values themselves, but these are replaced by ranks with which the actual test is performed. Thus, the calculation of the test is based solely on the order of the data (greater than, less than). The absolute distances between the values are not taken into account.

The z-value and the sample size (n) were used to calculate the correlation coefficient r. To assess the size of the effect the above-mentioned division of Cohen applies.

Significance limits

For the test procedures carried out, the following significance limits apply to the significance level τ for Kendall’s Tau and p for Mann-Whitney U test:

> 0.05 = not significant (n.s.)

≤ 0.05 = significant

≤ 0.01 = highly significant

4 Evaluation Results

This chapter presents and evaluates the results of the study. In section 4.1, the results of the Physical Activity Risk – Questionnaire, based on which the subjects were divided into the trained or the untrained group, are described. In sections 4.2 and 4.3, the HRV correlation calculation of the change of position test and the treadmill ergometric load test is shown. In section 4.4, results of the HRV comparison between trained and untrained subjects at the anaerobic threshold are presented.

4.1 Subjects questionnaire

In order to determine the current state of health of the subjects, the test persons were handed a questionnaire PAR-Q (Physical Activity Risk – Questionnaire, see also appendix) in which the regular physical activity (h/week) of the subjects was also recorded. As a regular activity endurance training (triathlon, running, cycling) which has been carried out over the last 3 months more than 6 hours a week has been defined.

Table 4 shows the evaluation of the questionnaire. In total, seven subjects indicated that they trained regularly endurance training units on a weekly basis. In six subjects, the weekly training included only endurance training units. And one of the seven subjects trained weekly in a gym. This weight training did not include any endurance units.

Table 4: Questionnaire evaluation of regular physical activity of the examined participants (n = 10)

Trainings specification	total (n = 10)	trained (n = 5)	untrained (n = 5)
Number of trainings per week (number)	3.2 ± 2.3 (0; 6)	5.2 ± 0.8 (4; 6)	1.2 ± 1.5 (0; 3)

∅ hours per training week (hours)	5.6 ± 4.7 (0; 12)	10.2 ± 1 (9; 12)	1 ± 1.3 (0; 3)
For x months (number)	13.7 ± 15.5 (0; 48)	22.8 ± 16.3 (6; 48)	4.6 ± 7 (0; 18)

(MW ± sd, Min; Max)

The regular activities of the 10 subjects could be summarized on running (ultra runs), cycling, and triathlon, and in one case on weight training. Based on the questionnaire, it was found that on average five of the subjects were regularly physically active 10 ± 1 h/week. For the other five subjects, the average regular physical activity was with a weekly amount of 2 hours far below the given weekly 6 hours, or even they did not do any regular physical activity.

4.2 Heart rate variability reliability during a change of position test

In this section the results of the 15-minute change of position test are shown in detail. The parameters described were each calculated over 5 minutes, resulting in 3 values per person and parameter. These were then assigned to the respective groups (untrained (P1-P5) and trained (P6-P10)) and summarized so that for each group and each parameter 3 mean values could be calculated.

As described in section 3.4, the Kendall's tau (τ) coefficient was calculated to find out if HRV is reliable or not. Table 5 shows the results of the calculated 3 mean values from the chosen parameters.

Table 5: Results of the Kendall's tau coefficient calculation from the change of position test 1 and test 2 in the untrained group and trained group

Reliability Change of position

Untrained	Change of position test 1					Untrained	Change of position test 2					Kendall's tau		
	P1	P2	P3	P4	P5		P1	P2	P3	P4	P5	τ	r	Significant
RMSSD (ms)						**RMSSD (ms)**								
0 - 5 min	87.10	56.80	35.60	56.90	27.60	0 - 5 min	75.60	x	57.40	109.20	169.10	0.497	-0.333	n.s.
5 - 10 min	36.90	38.70	37.30	42.50	35.80	5 - 10 min	45.10	x	50.60	24.60	40.60	0.164	-0.836	n.s.
10 - 15 min	61.00	72.50	40.20	62.30	27.20	10 - 15 min	112.70	x	50.20	79.20	114.20	0.497	-0.333	n.s.
pNN50 (%)						**pNN50 (%)**								
0 - 5 min	29.50	27.30	12.00	23.30	6.40	0 - 5 min	46.40	x	33.70	39.10	57.60	1.000	0.0	n.s.
5 - 10 min	9.60	9.10	4.90	1.80	5.20	5 - 10 min	19.20	x	22.70	4.80	15.30	0.333	0.497	n.s.
10 - 15 min	38.30	31.70	13.00	28.40	8.40	10 - 15 min	38.50	x	28.00	31.20	41.00	1.000	0.0	n.s.
LF/HF (%)						**LF/HF (%)**								
0 - 5 min	0.79	3.36	4.33	1.08	3.21	0 - 5 min	3.00	x	1.02	1.46	0.97	0.174	-0.667	n.s.
5 - 10 min	12.31	7.16	18.32	0.62	4.99	5 - 10 min	11.43	x	19.13	3.18	2.94	0.174	-0.667	n.s.
10 - 15 min	2.80	1.32	4.96	1.12	4.56	10 - 15 min	1.60	x	4.97	1.19	1.79	**0.042**	1.000	*

Trained	Change of position test 1					Trained	Change of position test 2					Kendall's tau		
	P6	P7	P8	P9	P10		P6	P7	P8	P9	P10	τ	r	Significant
RMSSD (ms)						**RMSSD (ms)**								
0 - 5 min	29.90	175.70	65.70	42.40	42.00	0 - 5 min	77.30	115.90	75.60	51.80	58.30	0.624	0.2	n.s.
5 - 10 min	24.10	61.10	97.80	30.80	39.50	5 - 10 min	49.90	47.60	72.70	29.90	63.40	0.327	0.4	n.s.
10 - 15 min	39.10	141.90	160.90	89.40	53.50	10 - 15 min	41.10	134.80	150.20	88.30	57.30	**0.014**	1.0	**
pNN50 (%)						**pNN50 (%)**								
0 - 5 min	9.90	55.70	36.00	22.10	22.40	0 - 5 min	20.20	52.40	24.60	28.30	37.00	0.142	0.6	n.s.
5 - 10 min	5.10	24.10	26.20	7.50	8.60	5 - 10 min	15.40	22.50	18.90	7.60	22.20	0.327	0.4	n.s.
10 - 15 min	14.80	55.30	52.80	22.70	27.60	10 - 15 min	10.30	54.10	43.60	38.30	37.20	**0.050**	**0.8**	*
LF/HF (%)						**LF/HF (%)**								
0 - 5 min	2.83	1.00	1.33	1.74	2.75	0 - 5 min	2.10	0.51	0.96	2.23	1.65	0.142	0.6	n.s.
5 - 10 min	11.97	3.69	2.38	8.71	7.67	5 - 10 min	1.41	1.79	1.33	11.75	3.89	0.327	0.4	n.s.
10 - 15 min	2.40	1.42	0.92	0.12	2.12	10 - 15 min	3.38	0.50	2.25	1.43	2.86	0.142	0.6	n.s.

P1-P5 = untrained, P6-P10 trained

Untrained Change of Position Test 1 and Retest

The results in Table 5 show that a significant result could not be found with all HRV parameters. The two parameters RMSSD and pNN50% does not correlate between test 1 and test 2 in the untrained group. For the value LF/HF no correlation is given, except during the last 5 minutes of the 15min period. There is a correlation r =1 ($\tau \leq 0.05$) with a mean effect between test 1 and test 2 in the untrained group.

Trained Change of Position Test 1 and Retest

The statistics in Table 5 show that even here in the trained group, almost none of the changes that have occurred during the HRV measurements have a statistical correlation. In detail, LF/HF does not correlate between test 1 and test 2. RMSSD and pNN50 shows almost no significance either, except for the last 5 minutes of the 15-minute period. RMSSD that quantifies the variation of one RR interval to the next indicates there is a correlation r = 1 ($\tau \leq 0.01$) with a mean effect between test 1 and test 2 in the trained group (. For the value pNN50, there is a correlation r = 0.8 ($\tau \leq 0.05$) with a strong effect between test 1 and test 2 in the trained group.

4.3 Heart rate variability reliability during the treadmill ergometric test

In this section the results of the treadmill ergometric exercise and the Conconi test are presented. Five parameters were chosen to determine the correlation between each subject's first and second Conconi tests. To figure out whether HRV is reliable or not, the Kendall's tau coefficient was calculated as described in Section 3.4.

Untrained group - Conconi test 1 and test 2

Table 6 shows the Conconi test results at the anaerobic threshold of the untrained group.

The values RMSSD and SD1 do not correlate between Conconi test 1 and test 2 in the untrained group. For the values TP, LF and HF, no correlation could be established since the individual values were too low (N.A). Valid for all mentioned parameters, no significant result is observed here.

Trained group - Conconi test 1 and test 2

Table 7 shows the Conconi test results at the anaerobic threshold of the trained group.

For the values TP, LF and HF, no correlation could be discovered since the individual values were too low (N.A). For the values RMSSD and SD1 there is a correlation both with r = 1 ($\tau \leq 0.042$) between test 1 and test 2 in the trained group. Figure 14 shows one of the subjects during the Conconi test.

Figure 14: Treadmill Conconi test

Table 6: Results of the Kendall's tau coefficient calculation from the Conconi test 1 and test 2 in the untrained group

Untrained	Conconi test 1					Untrained	Conconi test 2					Kendall's tau		
	P1	P2	P3	P4	P5		P1	P2	P3	P4	P5	τ	r	Significant
RMSSD (ms)	3.34	2.51	2.83	2.25	3.57	RMSSD (ms)	3.20	x	2.50	2.50	3.50	0.063	0.913	n.s.
TP (ms2)	1.20	0.70	0.38	0.36	1.14	TP (ms2)	0.90	x	1.06	0.46	1.99	0.497	0.333	n.s.
LF (ms2)	0.94	0.34	0.18	0.13	0.87	LF (ms2)	0.69	x	0.19	0.36	1.17	0.497	0.333	n.s.
HF (ms2)	0.17	0.18	0.15	0.11	0.14	HF (ms2)	0.15	x	0.74	0.06	0.22	0.497	0.333	n.s.
SD1 (ms)	2.37	1.78	2.01	1.59	2.53	SD1 (ms)	2.27	x	1.77	1.77	2.48	0.063	0.913	n.s.
Mean HR	178.88	171.90	169.32	163.92	181.76	Mean HR	178.47	x	168.40	164.50	180.66	**0.042**	**1.000**	*

Table 7: Results of the Kendall's tau coefficient calculation from the Conconi test 1 and test 2 in the trained group

Trained	Conconi test 1					Trained	Conconi test 2					Kendall's tau		
	P6	P7	P8	P9	P10		P6	P7	P8	P9	P10	τ	r	Significant
RMSSD (ms)	2.17	5.89	5.08	2.75	x	RMSSD (ms)	2.67	5.85	4.93	3.19	2.92	**0.042**	1.000	*
TP (ms2)	1.27	5.13	0.34	0.66	x	TP (ms2)	0.81	2.43	0.98	0.18	1.86	0.497	0.333	n.s.
LF (ms2)	0.64	0.63	0.13	0.25	x	LF (ms2)	0.07	1.33	0.16	0.06	0.60	1.000	0.000	n.s.
HF (ms2)	0.54	4.24	0.14	0.35	x	HF (ms2)	0.70	0.32	0.80	0.11	1.08	0.497	-0.333	n.s.
SD1 (ms)	1.54	4.18	3.60	1.95	x	SD1 (ms)	1.90	4.15	3.50	2.26	2.07	**0.042**	**1.000**	*
Mean HR	177.88	170.77	182.36	186.25	x	Mean HR	177.66	161.82	173.12	185.02	166.29	0.174	0.667	n.s.

4.4 Comparison of trained/untrained subjects

This part shows the results of the comparison from the HRV at the anaerobic threshold between trained and untrained subjects. As described in 4.3 five parameters were chosen. In this case, the Mann-U Whitney test provided information on whether there is a possible difference in HRV at the anaerobic threshold between the two groups.

The better result (the one where the anaerobic threshold was clearly reached) of each subject was taken from the first Conconi test and the second test for the evaluation. The reason for this was that not everyone on both tests reached his anaerobic threshold. Table 8 shows the results of the HRV at the anaerobic threshold resulting from the comparison between the trained and the untrained group.

All five parameters RMSSD, TP, LF, HF and SD1 show that there is no difference in the HRV at the anaerobic threshold between the trained and the untrained group. The results are not statistically significant.

Table 8: Results of the Mann-U Whitney test calculation from the Conconi test 1 and test 2 in the trained and untrained group

Trained						Untrained						Mann-Whitney U test		
	P6	P7	P8	P9	P10		P1	P2	P3	P4	P5	p	r	Significant
RMSSD (ms)	2.17	5.89	5.08	3.19	2.92	RMSSD (ms)	3.34	2.51	2.83	2.50	3.50	0.531	0.280	n.s.
TP (ms2)	1.27	5.13	0.34	0.18	1.86	TP (ms2)	1.20	0.70	0.38	0.46	1.99	0.531	0.280	n.s.
LF (ms2)	0.64	0.63	0.13	0.06	0.60	LF (ms2)	0.94	0.34	0.18	0.36	1.17	0.531	0.280	n.s.
HF (ms2)	0.54	4.24	0.14	0.11	1.08	HF (ms2)	0.17	0.18	0.15	0.06	0.22	0.403	0.373	n.s.
SD1 (ms)	1.54	4.18	3.60	2.26	2.07	SD1 (ms)	2.37	1.78	2.01	1.77	2.48	0.531	0.280	n.s.
Mean HR	177.88	170.77	182.36	185.02	166.29	Mean HR	178.88	171.90	169.32	164.50	180.66	0.531	0.280	n.s.

Statistical results revealed no significant results of the examined HRV parameters among trained and untrained subjects in this study. Therefore, the data of the HRV parameters, from the Conconi test, of the trained and the untrained group ones were visually compared in Figure 15 and Figure 16 to get a different insight. Figure 15 contains the parameters TP, LF, HF (ms^2) and Figure 16 contains the parameters RMSSD and SD1 (ms). The idea to add the HRV parameters of the respective two groups (each 5 probands) should give a visual impression if there may be a possible difference.

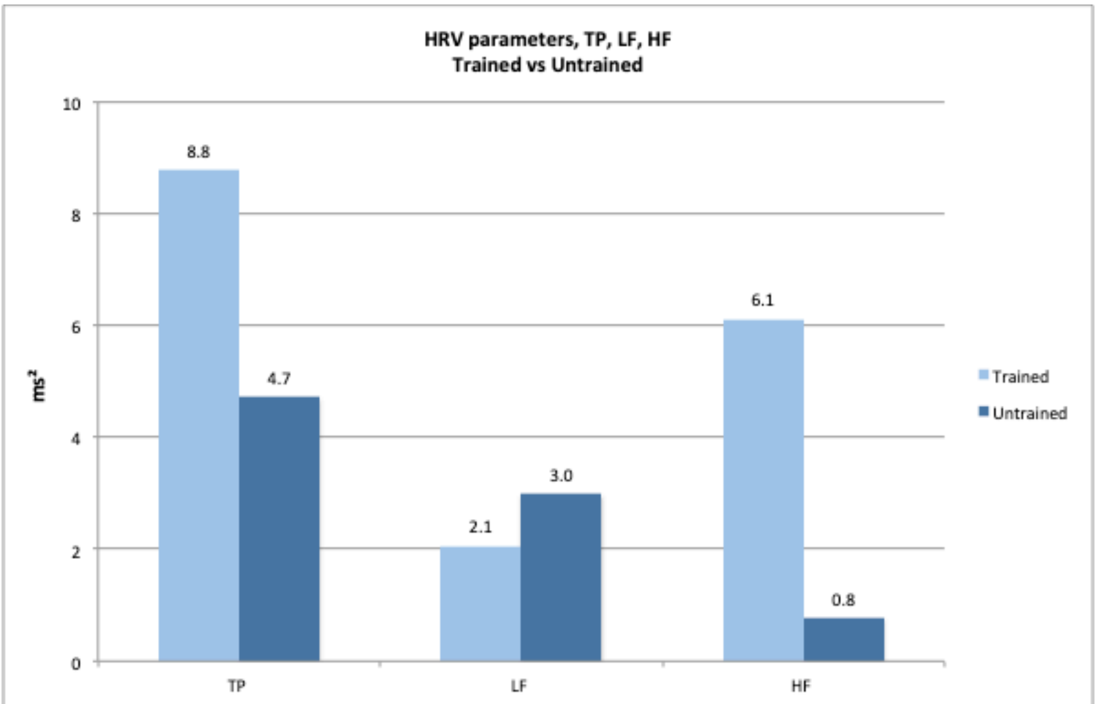


Figure 15: Comparison of the calculated sum of the individual HRV parameters (ms^2) (TP, LF, HF) at the anaerobic threshold between the trained and the untrained group.

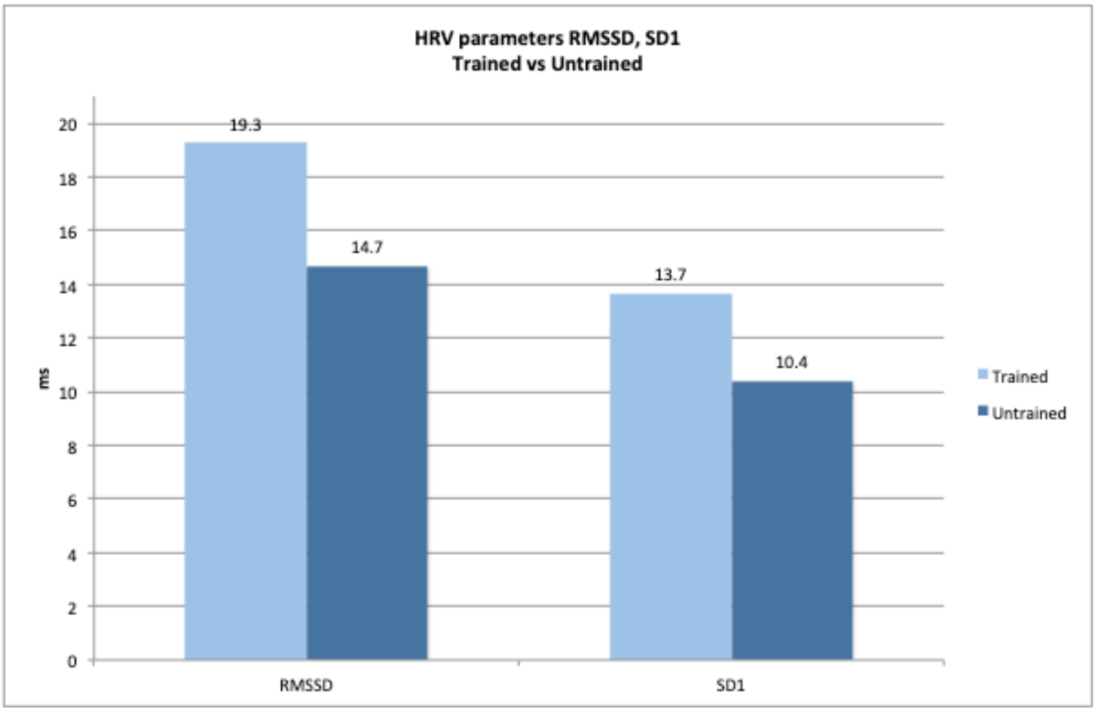


Figure 16: Comparison of the calculated sum of the individual HRV parameters (ms) (RMSSD, SD1) at the anaerobic threshold between the trained and the untrained group.

Visually, a clear difference among the groups can be clearly recognized for each parameter in both figures. Generally, higher values in HRV parameters suggest a healthier body and better endurance. The values from the parameters TP, RMSSD, SD1 are higher compared to the untrained group. These findings supports evidence from the literature that more endurance training is increasing the named parameters (Kiviniemi et al. 2007; Vesterinen et al., 2016).

Notably is the high difference between the trained and untrained group for the parameter HF in Figure 15. The HF band reflects parasympathetic activity and is referred to as the respiratory band, because it corresponds to the heart rate variations associated with the respiratory cycle (= respiratory sinus arrhythmia, the process where breathing in increases heart rate, and breathing out decreases heart rate) (Grossman & Taylor, 2007).A higher HF performance, as seen in the trained group, indicates that the vagal activity has been improved by the adaptive changes in nerve regulation that are caused by long-term physical training.

As well in Figure 15, the parameter LF is the only value that is higher in the untrained group than in the trained one. One reason for this may be the respiration rate as mentioned before in Chapter 2.4 Factors influencing heart rate variability. The LF band, although known to be enhanced by vagal activity, appears to provide mainly an index of sympathetic modulation and its changes.

In times of slower breathing rates, vagal activity can easily lead to heart rhythm oscillations that shift into the LF band (Charan & Deekshatulu, 1969; Tiller, McCraty, & Atkinson, 1996). Therefore, respiratory, efferent, vagal mediated effects are particularly prevalent in the LF band when respiratory rates are below 8.5 beats per minute or 7 seconds (Hirsch & Bishop, 1981; Tiller et al., 1996) or when one sighs or breathes deeply. Moreover, it is well known that athletes have slower respiratory frequencies (Bernardi & Piepoli, 2001).

It is to note that, the LF band is usually recommended to be recorded for two minutes (Shaffer, McCraty, & Zerr, 2014). In this study for the comparison between trained and untrained it was only recorded for one minute. Accordingly, in this case, the evaluation for the LF parameter in Figure 12 should not be overemphasized.

To sum the HF and LF up, results show an enhanced sympathetic activity (expressed by higher LF values) associated with a decreased vagal activity (expressed by lower HF values) in the untrained group.

5 Discussion

5.1 Interpretation

In this section, the results of the reliability of the change of position test and the treadmill ergometric exercise, as well as a possible difference between the trained und untrained groups are discussed.

The present study investigated the reliability of HRV during a resting situation (change of position test) and a treadmill ergometric exercise (Conconi test) in performance-oriented subjects and an untrained group (= Q1). Furthermore, a possible difference at anaerobic threshold among trained and untrained subjects was investigated (= Q2). In regards to Q1, it was found that the calculated parameters during both tests show no reliability. Regarding Q2 no statistical difference in the HRV between untrained and trained could be found.

Research Question 1

In order to investigate Q1 the Kendall's Tau (τ) correlation coefficient was calculated. The Kendall's Tau correlation coefficient measures the statistical relationship between the HRV parameters and provides information on the reliability of the measured HRV parameters. Effect sizes (r), to determine how strong the correlation is, were interpreted according to classifications (weak = $r > 0.1$, mean = $r > 0.3$, strong = $r > 0.5$; Cohen (1992)).

Reliability change of position test

Most of the results of the calculated parameters within the change of position test show no reliability. Only a few numbers indicate that they could be reliable parameters for this test. For example, the HRV parameter LF/HF shows a mean correlation from the test 1 and test 2 (the retest) in the untrained group in the second 5-minute lying phase, which proved to be significant ($r = 1$, $\tau = 0.04$).

On the other hand, the trained group shows other significant parameters recorded during the change of position test. In this case only the HRV parameters RMSSD and pNN50 showed a correlation between the two tests, but again only in the second 5-minute lying phase. RMSSD shows a high significant mean correlation between both tests (r = 1, τ = 0.01). pNN50 shows a strong correlation, which is statistically significant (r = 0.8, τ = 0.05).

However, it is needed to use a definitely larger sample size to check the reliability of HRV during the change of position test.

Reliability treadmill ergometric test

For the reliability of the treadmill ergometric test in the untrained group, no significant results could be discovered in this study. The HRV parameters RMSSD and SD1, which both reflect the parasympathetic heart activity, showed a certain (RMSSD τ = 0.08) and moderate (SD1 τ = 0.06) trend towards significance.

The statistics indicate that in the trained group during the treadmill ergometric test in both analyzed HRV parameters, RMSSD and SD1 (r = 1, τ = 0.042), a correlation between test 1 and the retest is present. From this it can be seen that the treadmill ergometric test of the trained group is probably reliable.

Research Question 2

In order to investigate the difference between trained and untrained at the anerobic threshold (Q2) the Mann-Whitney U test was used. To determine how strong the correlation is, the effect sizes were interpreted according to classifications (weak = r > 0.1, mean = r > 0.3, strong = r > 0.5; Cohen (1992)).

Comparison of trained/untrained subjects

After detailed analysis of the values obtained, no statistical difference in the HRV between untrained and trained could be found with the data available in this pilot study. However, it could be visually determined with two diagrams that a difference in HRV at the anaerobic threshold is present in both trained and untrained groups. Almost all of the evaluated HRV parameters in the trained group show distinctly higher values. These high HRV values reflect the increased performance and recovery ability of the trained group.

Specifically, the HF power parameter was much higher in the trained group (HF = 6.1 ms^2) than in the untrained group (HF = 0.8 ms^2). This indicates that the vagal activity has been improved by the adaptive changes in nerve regulation caused by prolonged physical training. Bernardi & Piepoli (2001) discovered that athletes have slower breathing rates. This was also reflected in the result, because LF, which is known to be enhanced by vagal activity (Charan & Deekshatulu, 1969), is the only parameter that has a higher value in the untrained group (LF = 0.8) as in the trained group (LF = 2.1).

5.2 Limitations

Even with precise and thorough prior planning, the implementation of such a study poses problems that could not be foreseen or avoided, and may have influenced the outcome of the study. These include technical difficulties (e.g. inaccurate heart rate measurement) or test subject failures or weaknesses in the study design. In the following section of this thesis, I would like to elaborate on these problems, sources of error and limitations in order to achieve the greatest possible transparency and to lay the groundwork for subsequent studies.

Sample size

The sample size of n = 10 is regarded as a limitation. For the correlation in the untrained group only data of n = 4 was used since a subject of the untrained group could attend the test only once. The group could be argued to be too small, since such a small number of participants might not be considered meaningful.

Untrained group

The criterion (weekly training less than 5 hours during the last 3 months) according to which the participants were allocated to the untrained group may be seen as too inaccurate. There are subjects in the untrained group who did not do any sport at all in the last 3 months, yet also some who did sport occasionally, but whose weekly training did not exceed 5 hours. The more hours of sport a week one is practising can affect the HRV. It is recommended for future research to more precisely determine the criteria for group allocation. As an adjustment criterion, for example, the measured maximum oxygen uptake (VO2max.) could be used, which is considered an objective measure of physical performance.

Conconi test

The Conconi test scheme is a non-invasive method that was used in this pilot study to determine the anaerobic threshold. It is an easy-to-apply and accurate method. In the literature it is controversial as to whether the Conconi test scheme is reliable or not. For example, in 1995 the *International Journal of Sports Medicine* stated that the Conconi test is unsuitable for the reliable evaluation of the anaerobic threshold. Conconi et al. (1996) reported that less than 1% of the tests were unsuccessful when performed by experienced athletes and the training intensity gradually increased. In this study, the anaerobic threshold was not found in every test. However, there were also some tests where both tests led to the same result. Nevertheless, it is recommended for future research to determine the anaerobic threshold with a more recognized test such as the blood lactate test. In this case, an accurate result would be given.

HRV

HRV has its own limitations, as stated in section 2.4, depending on the condition of the subject, such as fatigue, rest, and food intake and so on, which can all affect HRV. With the given procedures before the test, an attempt was made to ensure a uniform test. However, running a uniform test is only moderately possible. Therefore, this must also be counted as a limitation.

6 Conclusion

The main purpose of this pilot study was to determine differences in HRV in trained and untrained subjects at the anaerobic threshold. In addition, possible correlations of HRV during a resting situation (change of position test) and potential correlations during an ergometric exercise (Conconi test) were investigated.

No significant correlations could be found in HRV during the change of position test and also not during the treadmill ergometric exercise in both investigated groups. Only for the treadmill ergometric exercise in the trained group, test 1 and the retest can be considered as reliable. Nevertheless, the untrained group has a slight trend to significance. In another study conducted by Sima et al. (2017), a substantial reliability in the time and frequency domain parameters such as LF, TP an LF/HF could be verified during the change of position test. Furthermore, parameters that are related in that they have a parasympathetic influence, RMSSD and HF, showed moderate reliability. The lack of clear reliability of this study can be attributed to the fact that the number of subjects (n= 10) is too small.

The second research question of this study deals with possible differences in HRV among trained and untrained subjects at the anaerobic threshold. Most results did not indicate differences of statistical significance. However, the visual comparison of the calculated sum of the individual HRV parameters (TP, LF, HF, RMSSD and SD1) and its results confirm the findings of Jimenez Morgan & Molina Mora (2017) and Hull et al. (1994). This proves that untrained people have lower heart rate variability and that regular exercise increases the HRV in athletes. Therefore, through regular endurance training sessions diseases (e.g. Myocardial infarction, diabetes mellitus, chronic heart failure…) can be detected earlier as well as prevented.

Outlook

The study, together with the limitations indicated, should be an excellent basis for further studies with a same or similar goal. Especially if in subsequent studies the number of subjects is more generous, the result should be clearer and possibly more significant. An even more precise narrowing of the untrained group may also contribute to a possibly significant result. Furthermore, a blood lactate test would be more meaningful since its reliability is already approved in many investigations.

In summary, further investigations into HRV reliability during exercise would be beneficial, particularly for the development of HRV-related training concepts.

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Appendix

A. PAR-Q

PAR-Q (Physical Activity Risk – Questionary)

Hast du in den letzten 3 Monaten regelmässig (ø mehr als 6 Stunden wöchentlich) ein Ausdauertraining betrieben? O Nein O Ja ___ Anzahl Trainings pro Woche / ø ___ Std. pro Trainingswoche / Seit ca. ___ Wochen/Monate		
Hat dir jemals ein Arzt gesagt, du hast „etwas am Herzen" (Herzschwäche oder ähnliches) und dir Bewegung und Sport nur unter medizinischer Kontrolle empfohlen?	Nein O	Ja O
Hat dir jemals ein Arzt Medikamente gegen hohen Blutdruck oder für ein Herzproblem verschrieben?	Nein O	Ja O
Bist du Diabetiker (Zuckerkrank)?	Nein O	Ja O
Leidest du unter Asthma oder chronischer Bronchitis?	Nein O	Ja O
Hast du in den letzten 4 Wochen Zigaretten geraucht?	Nein O	Ja O
Warst du in den letzten 3 Wochen krank im Bett und/oder hattest du Fieber?	Nein O	Ja O
Ist dir aufgrund persönlicher Erfahrung oder ärztlichen Rates ein weiterer Grund bekannt, der dich davon abhalten könnte, ohne medizinische Kontrolle Sport zu betreiben?	Nein O	Ja O

Der Unterzeichnende bestätigt die Richtigkeit der obenstehenden Angaben, ist vollumfänglich über den Ablauf und die Durchführung des Tests (Lagewechseltest und Conconitest) informiert worden.

Datum: Körpergröße: ______cm_____

Geb. Datum: ___________________ Gewicht: ______kg_____

Name/Vorname: Unterschrift:

B. Raw data / Evaluation files

All the raw data files (*.hrm and *.pdd) from the polar watch can be found on the CD as well as all evaluation files (*.txt and *.pdf) from the trained und untrained group during the Conconi and change of position test.

The evaluation data from the determination of the deflexion point / anaerobic threshold can be found in the *.xls file on the CD.