Kuno Hottenrott (eds.)

Heart Rate Variability: Methods and Applications in medicine and physical exercise

Book of abstracts

KARL WERDAN, HENDRIK SCHMIDT, RALF HENNEN & URSULA MÜLLER-WERDAN

Heart Rate Variability - Established Indications and new Perspectives in Medicine

Summary

Many of the disease entities we are facing day by day are characterized by a pronounced sympathetic-parasympathetic imbalance (e.g. acute coronary syndromes, chronic heart failure, diabetes mellitus). The assessment of heart rate variability is valuable tool to describe this autonomic dysfunction and derive prognostic implications.
The present manuscript summarizes the current applications of heart rate variability in internal medicine. Furthermore, future aspects of heart rate variability usage are discussed. Special paragraphs focus on heart rate variability and aging as well as potential mechanisms, the autonomic dysfunction is based on.

OLAF HOOS

Power Spectrum Analysis of Heart Rate Variability in Sports – Methods and Applications, Possibilites and Limitations

Summary

Power spectrum analysis of heart rate variability (HRV-PSA) has been verified as a non-invasive marker of cardiac autonomic modulation at rest and is gaining increasing attention in Sports Science. In this area, HRV-PSA is currently used as a non-invasive tool for a variety of purposes, such as quantification of autonomic modulation during exercise and recovery, assessment of autonomic changes associated with short- and long-term exercise training, monitoring of training load, and detection of overreaching and overtraining. Despite its widespread use, inconsistent and confounding results are often reported, especially during exercise conditions. In addition to non-neural factors and a possible dissociation of spectral estimates and autonomic modulation, methodological limitations have to be considered, that strongly affect the traditional HRV spectral techniques of Fast-Fourier-Transform and Autoregressive Modelling. Important determinants of these methods are the non-stationarity and uneven sampling of the RR-interval time

series, the spectral resolution, and the signal-to-noise-ratio in specific settings. Alternative spectral methods, such as Coarse Graining Spectral Analysis (CGSA) and Continous Wavelet Transform (CWT), are promising as they overcome some of the traditional limitations. Thus, CWT provides time-continous frequency information and permits tracing of transient episodes, while CGSA proves valuable in verifying expected changes of autonomic activity during moderate exercise conditions. Future research with larger sample sizes using traditional and alternative spectral analysis methods as well as non-linear techniques are necessary to further elicudate the benefit of HRV as a non-invasive marker of cardiac autonomic modulation in sports-related activities. Due to the complexity of both the underlying physiology and the analysis methods interdisciplinary cooperations between researchers involved in sports science, cardiology, and biomedical engineering is desirable with respect to HRV-PSA.

HANS D. ESPERER

Nonlinear Analysis of Heart Rate Variability in Sports. Principles, Practice and Pitfalls

Summary

In physics, nonlinear techniques have been long used for investigation into nonlinear dynamical systems. The motivation to make use of these tools in the context of heart rate variability (HRV) was originally driven by efforts to demonstrate the chaotic nature of the underlying dynamics. Although these attempts have proved elusive, in the past decade, nonlinear methods have been shown to be extremely valuable in HRV analysis. The novel methods bear a surplus of important information on heart rate dynmics not conveyed through traditional summary statistics. Thus, it is only natural that biomedical research is increasingly attracted by these advantages. Neverthless, although some of the nonlinear techniques, such as Poincaré and recurrence plots, may be intuitively comprehended by the very beauty of their visual results, others are less appealing and recquire a sound theoretical basis for appropriate use. In this article, we try to lay this basis and review selected methods of nonlinear dynamics, which may be of value in sports and training sciences. Emphasis is put on measures of fractality and complexity, such as power law scaling, detrended fluctuation analysis, correlation dimension, Lyapunov exponent and approximate entropy. We also describe the methods of qualitative and quantitative Poincaré and recurrence plot analysis. The mathematical and pyhsiological background of each method is detailed. The applications and

potential pitfalls of the various methods are discussed insofar as they are relevant to sports and training.

HERBERT LÖLLGEN, ISABELLE SAURE & DEBORAH LÖLLGEN

Autonomic Function and Cardiac Performance Measures During Postural Changes and Simulated Zero Gravity

Summary

The possible simulation of weightlessness is illustrated shortly together with the corresponding hemodynamic changes. The thoracic blood shift during weightlessness leads to various cardiopulmonary changes. Heart rate variability (HRV) is increased during head down tilting (mean HRV). Methodological problems do explain the divergent results in most studies on this topic. Standardization while measuring HRV is strongly recommended. Longer lasting weightlessness is a model to analyze effects of immobilization on men.

KUNO HOTTENROTT & RENÉ SCHWESIG

Dynamics of Running Speed and Lactate Concentration During a 40 minute Treadmill Exercise Test at Steady State Conditions Assessed by Means of Heart Rate Variability

Summary

***Background**: In endurance training control the assessment of the individual fitness state at the aerobic-anaerobic threshold and the determination of the maximal steady state of lactate metabolism are of paramount importance.*
Usually, the parameters used for training control are defined in terms of heart rate and do not take into account individual speed or performance characteristics.
So far, in endurance training, the correlation between steady state indicators based on physiologic requirements and physically defined performance parameters have not been systematically studied.
***Objective**: We sought to determine the dynamics of both lactate concentration and physical performance in endurance training during steady state conditions*

defined in terms of heart rate. Therefore, in 22 male and 22 female sports students, physical exercsie testing was performed at aerobic-anaerobic crossover for 40 minutes. We used a treadmill (h/p cosmos pulsar 3.0), whose speed automatically adjusted to the heart rate of the athlete under test. In each study participant, the following parameters were assessed: treadmill speed (as a measure of running speed) and lactate concentration. The latter was determined during the pre-exercise resting state and during the test at the 10^{th}, 20^{th}, 30^{th} and 40^{th} minute.

***Results**: During exercise testing, the female athletes exhibited a significant decrease in treadmill speed from 10.61 ± 1.66 km/h (10^{th} min) vs. 9.29 ± 1.64 km/h (40^{th} min). The male athletes showed a similar decrease in treadmill speed: 11.28 ± 1.64 km/h (10^{th} min) vs. 10.02 ± 1.74 km/h (40^{th} min), $p < 0.01$. Simlutaneously, a significant ($p < 0.01$) decrease of the lactate concentration was observed in both the females: 3.76 ± 1.41 mmol/l (10^{th} min) vs. 2.74 ± 0.93 mmol/l (40^{th} min), and the males: 3.85 ± 1.32 mmol/l (10^{th} min) vs. 2.66 ± 1.08 mmol/l (40^{th} min). There were no sex-related differences among the parameters investigated.*

***Conclusions**: While running speed remained constant at maximum steady state defined in terms of lactate concentration, a siginificant decrease was noted when steady state was defined in terms of heart rate. Overall, our results demonstrate that there are important differences between indicators of cardio-pulmonary performance and parameters of muscle metabolism. These differences have to be taken into account regarding work load control in endurance training.*

HENNING RÖTTGER, KATJA KUHN & PETRA PLATEN

Heart rate variability (HRV) during progressive cycling load in 14 to 16 year old male athletes

Summary

***Introduction:** The purpose of the present study was to examine changes in HRV during progressive cycling load in a group of athletic male adolescents and to relate vagal modulation to metabolic and respiratory shifting. The main purpose was to analyse the use of HRV as a non-invasive measurement of physical performance in adolescents.*

***Methods:** Healthy male soccer players (n = 31) were tested by standardized cycling ergometric procedure with starts at 30 watts and increasing steps of 40 watts every three minutes until subjective exhaustion. Metabolic changes, respiratory alterations ($\dot{V}O_{2max}$, $\dot{V}O_{2max}$ rel., respiratory equivalent), and vagal modulation (SD1, RMSSD) were determined every last minute of each step of*

loading. Performance (watts) at HRV-minima (minimum of SD1 and RMSSD with a subsequent rise to the end of the test: P_HRVmin) were correlated (Pearson correlation coefficient [r]) with the maximal performance (P_max), performance at 2, 3 and 4 mmol/l lactate (P_L2, P_L3, P_L4) and at the point of the procentually highest increase of the respiratory equivalent to the end of the test (P_RE).

***Results**: SD1 (ms) and RMSSD (ms) generally presented rapid decreases in the beginning of exercise with a levelling off at moderate loads. 20 of 31 subjects showed HRV-minimum averaging at 3,6 mmol/l lactate, 90 % HR_{max}, 78 % ($\dot{V}O_{2max}$ rel., 76 % P_max, 95 % P_L4 and 90 % P_RE. A significant correlation was shown for P_HRVmin and: P_RE (r = 0,81 ,p < 0,001), P_max (r = 0,86, p < 0,001) and P_L3 and P_L4 (0,73, p < 0,001).*

***Conclusion:** The data indicate the valuability of the non-invasive measurement of the HRV for the evaluation of physical performance in moderate intensive aerobic-anaerobic metabolic stages in endurance trained adolescent males.*

KATJA KUHN, HENNING RÖTTGER & PETRA PLATEN

Performance of Heart Rate Variability (HRV) before and after an exhausting cycle ergometer test in male adolescents

Summary

***Introduction:** Especially in performance-orientated adolescents the measurement of HRV could serve as a tool to investigate recovery after intensive training or competition periods.*

Therefore the purpose of this study was 1st to investigate HRV after an exhausting cycle performance test in young soccer players and 2nd to analyse the influence of endurance capacity on parameters of HRV as indicates of recovery.

***Methods:** 31 male adolescents (Age: 15,0 ± 0,9 years; Height: 174,0 ± 0,1 cm; Weight: 63,3 ± 9,7 kg) served as subjects. The subjects performed a cycle test with incremental intensities until exhaustion. Before the test, and after a 10-minute recovery period on the bicycle at 1 W/kg bodyweight the subjects performed an investigation to record autonomic regulation. RMSSD (ms), pNN50 (%) and LF/HF-ratio (%) served as parameter for the evaluation of recovery.*

***Results:** Previous to the test RMSSD and pNN50 were on a significantly higher level as compared to after the test. Furthermore, the LF/HF-ratio showed a significant higher level after the testing situation. Previous to the*

test, no effects of endurance level could be demonstrated when comparing the two subgroups (group1 (n = 9): maximal load < 4,0 W/kg LBM; group 2 (n = 8): maximal load ³ 4,5 W/kg LBM). After the test, however the less fit group showed a higher parasympathetic level than the fitter group.
Discussion and Conclusion: *The 10-minute recovery phase had apparently not been sufficient to restore the vagal base level. Despite the attempt of differentiation by endurance capacity, the subjects seemed too homogeneous to determine differences in autonomic regulation during rest previous to the test. The lower vagal activity after the test in the fitter group could be the result of a longer exercise time as result of their higher maximum power.*

HANS-CHRISTIAN ESPERER, PEGGY HOLLENBACH & HANS D. ESPERER

Are Short-term Indices of Heart Rate Variability Reliable Surrogate Markers of Long-term HRV?

Summary

Background: *Heart rate variability (HRV) is attracting the attention of the scientific community in an exponential fashion as can be inferred from the growing number of HRV articles being published every year. However, often conflicting results question the usefulness of this interesting research tool. Particularly, the traditional HRV measures may give rise to confusion, if their limitations are not taken into account. Thus, time-domain indices are often assessed from ECG-recordings of short or very short duration and inferences are made that are valid for long-term results, but may not hold for short-term data.*
Objective: *We therefore tested the hypothesis that, in healthy individuals, HRV indices obtained from short-term recordings are not reliable surrogate markers of long-term HRV.*
Methods: *We performed 24-hour Holter monitoring in 40 healthy middle-aged volunteers and determined the following HRV indices: SDNN, SDANN, sNN50, and rMSSD from the whole 24-hour recording period (x-24-h), and from recordings obtained for four hours during day time (x-d), and night time (x-n), respectively. We also determined the circadian amplitude of the HRV indices investigated.*
Results: *As expected, SDNN-d, SDNN-n, SDANN-d, and SDANN-n were not or only very weekly correlated with the respective 24-hour SDNN or SDANN index. In contrast, sNN50, and rMSSD from both day time and night time recordings showed significant and fairly strong correlations with the respective*

24-hour indices. The circadian amplitudes of SDNN-24-h, SDANN-24-h, and sNN50-24-h were significantly larger than that of rMSSD-24-h.
Conclusions: *Neither SDNN, nor SDANN, nor sNN50 determined from short-term recordings can be used as a surrogate marker for the respective 24-hour HRV index. Although the group mean values of rMSSD from day-time and night-time recordings did not differ significantly from each other or from rMSSD-24-h, in individual cases, the presence of a significant circadian amplitude may limit the usefulness of rMSSD as a reliable short-term surrogate of long-term rMSSD.*

HANS D. ESPERER, HANS-CHRISTIAN ESPERER, BABETTE SCHÄDLICH & KUNO HOTTENROTT

Determinants of Poincaré Plot Patterns from ECG Recordings of Very Short Duration

Summary

Background: *Poincaré plots are currently used in qualitative analysis of heart rate variability (HRV), and though the patterns (PoPPs) manifesting on these plots have been defined for 24-hour Holter recordings, they are increasingly used for analysis of short-term recordings. While the principles governing the appearance of highly symmetric PoPPs, such as the torpedo pattern, may well hold for short-term recordings, they may be invalid with respect to more complex morphologies, such as the comet pattern. Thus, it is not known whether, in individuals with normal HRV, a comet shape will manifest in recordings comprising only a few beats.*
Objectives: *We investigated the PoPPs generated from very short R-R interval series in an attempt to define the spectrum of resulting morphologies and identify their determinants. We specifically tested the hypothesis that a comet morphology arises only in the presence of a sufficiently broad range of R-R intervals and a specific heart rate (HR)-HRV relationship.*
Methods: *Ten healthy middle-aged (49 - 67 ys) men (n = 6) and women (n = 4) with SR and normal 24-hour HRV underwent a specific test protocol for induction of a broad range of autonomic responses. During the test, ECGs of 15 - 17 min length were recorded from each participant and used as a baseline (NN_base), from which 5 to 7 short segments (NN_seg), each comprising 60 NN-intervals, were randomly selected and submitted to time domain and phase domain HRV analysis.*
Results: *While the PoPPs generated from NN_base showed a typical comet in all cases, the NN_segs (n = 53) exhibited a comet pattern in 49 %, and a non-comet morphology (i.e. broad ellipse, inverse comet, transitional forms) in*

the remaining 41 %. The following determinants of the PoPPs observed were identified: 1) Comet: a) large HR range, b) normal instantaneous HRV, and c) a negative quadratic relationship between HR and instantaneous HRV; 2) Inverse comet: a) large HR range; b) normal instantaneous HRV, and c) a negative logarithmic relationship between HR and instantaneous HRV; 3) Elliptical and other non-comet patterns: a) normal instantaneous HRV, b) small HR range, c) no correlation between HR and instantaneous HRV.
Conclusions: *In individuals with normal HRV, ECG recordings comprising 60 R-R intervals produce various Poincaré plot patterns that reflect different relationships between heart rate and instantaneous HRV. A typical comet shape will arise only in the presence of a large HR range and a nonmonotonic relationship between HR and beat-to-beat variability. The physiologic processes underlying these observations deserve further elucidation.*

HENRY SCHULZ, ANDRÉ PECOVNIK, FRANZISKA BOCHMANN & HERMANN HECK

Influence of Heart Rate Variability on the Polar OwnIndexTM. A Simulation Study

Summary

The Polar OwnIndex^{TM} Test predicts maximal aerobic power using artificial neural network calculation. The objective of the study was to quantify the influence of input features on the OwnIndex (OI).
Methods*: 2592 OI measurements were conducted using the heart rate monitor M52 (Polar Electro, Finland). The background variables gender (male, female), age (20, 40, 60 years), height (150, 170, 190 cm), weight (50, 70, 90 kg) varied as well as physical activity level (low, middle, high, top). Different RR interval signals were generated using a special personal computer software: Heart rates were 40, 60, 80 and 100 min^{-1} each with heart rate variability (low, middle, high; RMSSD from 6 to 175 ms).*
Results*: On the average OI values for men and women were nearly the same (M: 44.5 ± 12.2 ml min^{-1} kg^{-1}; W: 44.2 ± 13.0 ml min^{-1} kg^{-1}). The greatest influence on OI had physical activity level. The effect of age was little (men 0.2%, women 0.4% decrease per year >30). In some physical activity levels OI increased with higher heart rate. Heart rate variability had no influence on OI.*
Conclusion*: The effects of background variables and RR measurements on OI are partly different from findings in the literature. Therefore, the usability of the OwnIndex Test as an indirect method to determine maximal aerobic power seems to be questionable.*

ANDREA HORN

Reliability of Heart Rate Variability Measurements, Inter- and Intraobserver Variability.

Summary

Background: *Heart rate variability (HRV) analyses in the field of sportsmedicine or training science mostly focus on short-time analyses of young healthy and often highly trained persons.*
Objective: *This investigation aimed to assess firstly the overall reliability of HRV measures in a healthy male population of biological peak-performance age (study 1) and secondly to discriminate the dimension of the intraobserver-reliability and objectivity on HRV analysis (study 2).*
Methods*: study 1: Reliability and variation (ICC, VK) of supine heart rate (HF) and HRV were assessed for 59 healthy males (26±4yr; 183±7cm; 80±9kg) using a test-retest design with four measurements at different days. study 2: Inter- and intraobserver ICC and VK were estimated for 13 subjects with good experience in short-time HRV analysis. Each subject analysed 12 15-minute RR-recordings (random sample of study 1) at four different days in a fully blinded and randomized design. HRV measures were calculated for 256 RR-intervals (RR-I) as standard deviation of RR-I (RR_{SD}, ms), instantaneous (SO_L, ms and normalized to average RR-I SO_L/RR_{MW}) and longterm fluctuation (SO_W, ms) in two dimensional poincaré plot.*
Results*: In the healthy young males all repeated measures of HF and HRV were well correlated (ICC) but little consistent over time (VK). The observer related variation accounted for ca. 1/3 of the overall variation with superior intraobserver reliability vs. objectivity. The results of both studies are presented in the table below.*

	overall reliability		**intraobserver reliability**		**objectivity**		
measure	**ICC**	**VK (%)**	**ICC_{intra}**	**VK_{is} (%)**	**ICC_{inter}**	**VK_{bs} (%)**	
		med (25/75%)		med (25/75%)		med (25/75%)	
HF	0.76**	6.5 (4.9/ 9.0)	0.97**	1.0 (0.6/ 2.6)	0.96**	2.2 (1.5/ 3.4)	++
RR_{SD}	0.61**	18.5 (12.3/27.8)					
SO_L	0.72**	21.8 (14.0/32.1)	0.98**	2.9 (1.0/ 7.7)	0.97**	6.7 (5.6/10.8)	++
SO_L/RR_{MW}	0.68**	18.0 (13.8/28.0)					
SO_W	0.61**	18.9 (13.3/28.6)	0.94**	6.2 (1.8/ 10.4)	0.94**	9.6 (7.3/12.4)	+

Correlation *p<0.05; ** p<0.01; +p<0.05; ++ p<0.01 ; Wilcoxon test for VK_{is} vs. VK_{bs}

Conclusions*: The observer should be well educated and kept constant in particular within HRV studies of young healthy persons because of their distinct autonomic and especially vagal activity and consequently their mostly non-stationary RR-series.*

OLAF HOOS, STEFFEN GLÄSER & HANS-MARTIN SOMMER

Artefacts in Ambulatory Heart Rate Variability (HRV) Measurements During Treadmill Running

Summary

Analysis of heart rate variability (HRV) during exercise with ambulatory HRV systems is often difficult due to excessive motion artefacts resulting from electrode and subject movement. The object of this study was to assess the effect of running speed on chest-belt movement and the relative frequency of artefacts in RR-interval tachograms assessed by Polar S810i HRV-measurement system during treadmill running. 12 healthy male subjects ran for 5 minutes at two different running speeds (10 km/h and 14 km/h) on a motor driven treadmill. RR-intervals (Polar S810i) and two-dimensional chest-belt movement (for 10 seconds, frontal plane, Simi Motion) were assessed at both speeds. RR-artefacts were defined as RR-intervals varying more than 30 % from preceeding ones and their relative frequencies (%) were correlated with time- (max. amplitude (maxA), mean and maximum velocity (MeanV, maxV)), and frequency domain (Peak frequency (PeakF)) parameters of chest belt movement in vertical and horizontal direction of the frontal plane. Mean relative artefact frequency was slightly but not significantly increased with higher treadmill speed (10 km/h: 6.65 % ± 5.42 % vs. 14 km/h: 7.83 % ± 7.10 %), while all time- and frequency domain parameters of chest-belt movement increased significantly ($p < 0.05$) with increased treadmill speed. MaxA of chest-belt movement was significantly ($p < 0.05$) greater for horizontal direction compared to vertical direction while the opposite occurred for PeakF. Low to medium non-significant correlations ($-0.48 = r = 0.55$) between parameters of chest-belt movement and mean relative artefact frequency were detected. It is concluded that although difficult RR-detection conditions are present during running, other factors than chest-belt movement in the frontal plane must be considered as the primary cause of RR-interval artefacts.

OLAF HOOS, LENA KÜNKEL, MANFRED BETZ & HANS-MARTIN SOMMER

Effects of a Combined Endurance Exercise and Dietary Program on Heart Rate Variability (HRV), Quality of Life and Endurance Capacity in Mildly Obese Adults

Summary

The effect of moderate-intensity endurance exercise (walking) and mild calorie restriction on heart rate variability (HRV), quality of life and endurance capacity were investigated in 18 mildly obese subjects (15 female, 3 male) aged 37.9 ± 11.0 years with a body mass index (BMI) of 29.0 ± 3.2 kg/m^2 and 34.6 ± 4.1 % of body fat. The subjects participated in a 12-weeks program aimed at inducing a negative energy balance by increasing physical activity (aerobic walking exercise) and modifying eating behaviour. Besides anthropometric variables (BMI, % of body fat), blood pressure, quality of life (Short-Form Health Survey (SF-12)), endurance capacity (UKK-Walking Test) and time (MeanRR, RMSSD, SD1) and frequency domain (total power (TP), low- (LF) and high-frequency power (HF)) measures of HRV were calculated before and after the 12-weeks program. HRV-parameters were both assessed for 3 min of supine resting and for 3 min in response to active standing. After the 12-weeks program, significant decreases ($p < 0.01$) in BMI, body mass, % of body fat, and systolic and diastolic blood pressure were accompanied by significantly ($p < 0.01$) increased quality of life (both mental and physical aspects of SF-12) and endurance capacity. No significant changes for HRV-parameters in supine position could be obtained, while a significant ($p < 0.05$) reduction in LF-Power and a trend ($p = 0.10$) towards a more balanced sympathovagal response to active standing was observed after the intervention. Thus, the combination of aerobic walking exercise and mild calorie restriction led to positive changes in cardiovascular risk factors, aerobic capacity, quality of life and a more balanced adjustment to orthostatic stress, and induced an improved antagonistic control of the ANS.

OLAF HOOS, ELISABETH VOCKEROTH, DIRK SCHARLER & HANS-MARTIN SOMMER

Effects of Laser acupuncture on Heart Rate Variability in Healthy Adults

Summary

The object of this study was to assess the effects of laseracupuncture (low-level-laser therapy) applied at Yintang (EX HN3) point on sympathetic and parasympathetic modulation by time- and frequency domain analysis of short-time heart rate variability in healthy, physically active subjects during supine resting conditions. 10 male and 10 female healthy subjects were randomly assigned to two groups: LG (laseracupuncture group) and CG (control group). All subjects were free of cardiovascular diseases and were required to be well rested before the experiment. Laseracupuncture was applied to the EX HN3 point for LG while for CG pseudo-acupuncture without laser application was applied to the same point over the same time. HRV was calculated for 128 seconds before, during and after treatment. Stimulations of the EX HN3 acupuncture point provoked very different individual responses: Some subjects clearly showed increased vagal modulation while others responded by sympathetic augmentation. Statistically, no overall significant change in time and frequency domain measures of HRV could be revealed compared to baseline measurements. It was concluded that an application of laseracupuncture on EX HN3 point might not be sufficient to provoke a homogenous modulation of sympathetic and parasympathetic nerve activities in healthy subjects at supine rest. Further studies are warranted to clarify the influence of point and power of laser application as well as the influence of psychophysiological state and baseline-HRV of the subjects.

KRISTIN RINGEL, HENNER MONTANUS, KARL WERDAN & KUNO HOTTENROTT

Influence of physical fitness on heart rate variability in patients suffering from cardiac disease

Summary

Background**:** *There is consensus on physical training as playing an important role in the prevention and rehabilitation of cardiovascular diseases. While earlier researchers were interested in studying parameters of physical performance, there has been a paradigm shift in favour of the study of the autonomic nervous system (ANS). Hence, indices of heart rate variability (HRV), that have been shown to be valuable in cardiac risk stratification, are increasingly used in sports and training sciences. Numerous studies have shown that reduced HRV is associated with a poor outcome in various populations. Theoretically, improvement of compromised ANS activity through physical training should have a positive impact on prognosis and manifest in an increase of HRV.*

Objectives*: Therefore, we studied the effects of moderate physical training on both HRV and physical performance in patients suffering from congestive heart failure and healthy individuals.*

Methods: *We performed a quasi experimental study in 15 individuals with congestive heart failure and 15 age-matched healthy volunteers. Each of the study participants underwent a three-month period of physical training. Of importance, the training intensity was individually tailored and consisted of neuromuscular conditioning and endurance training elements. Prior to and after the training period several HRV indices and parameters of physical performance were measured.*

Results: *In both the patients and the volunteers, the training resulted in a significant increase of physical performance and a significant reduction of mean heart rate and an increase in heart rate reserve. In contrast, other HRV indices, such as RMSSD, pNN50 and SD2, did not exhibit significant changes.*

Conclusions*: A short training period of three months does not only lead to an increased physical fitness, but also results in a reduced heart rate, which is a benign phenomenon as to cardiac performance and prognosis. However, it is also concluded that three months of training may not suffice to induce autonomic alterations strong enough to manifest in altered indices of short-term HRV.*

HENDRIK SCHMIDT, RALF HENNEN, PATRICK TYMIEC, ROLAND PRONDZINSKY, MICHAEL BUERKE, URSULA MÜLLER-WERDAN, DIRK HOYER & KARL WERDAN

Prognostic Relevance of Heart Rate Variability in Multiple Organ Dysfunction Syndrome

Summary

***Background**. Multiple organ dysfunction syndrome (MODS) is the sequential failure of several organ systems after a trigger event, like sepsis or cardiogenic shock. Mortality is high, up to 70%. Autonomic dysfunction may substantially contribute to the development of MODS. Our study aimed to characterize the spectrum of autonomic dysfunction of critically ill MODS patients and whether autonomic dysfunction predicts mortality in MODS.*
***Methods**. We carried out a prospective cohort study in a twelve-bed medical intensive care unit of a university center. Ninety consecutively admitted score-defined (APACHE II score) MODS patients were assigned to this study. Heart rate variability as a marker of autonomic funktion was assessed. The patients were followed up for 28-day mortality.*
***Results**. Almost all indices of heart rate variability were attenuated in comparison to normal range data. lnVLF predicted 28-day mortality best in the entire cohort of patients.*
***Conclusion**. Autonomic function of MODS patients is blunted and this attenuation has prognostic implications. The extensive influence of MODS on autonomic function overwhelms and masks the well-known age dependancy of autonomic function seen in healthy persons.*

HENDRIK SCHMIDT, RALF HENNEN, ALEXANDER KELLER, KUNO HOTTENROTT, DIRK HOYER, ROLAND PRONDZINSKY, MICHAEL BUERKE, URSULA MÜLLER-WERDAN & KARL WERDAN

Heart Rate Variability and Therapeutic Consequences in MODS Patients

Summary

***Background**. The multiple organ dysfunction syndrome (MODS), a subsequent failure of two or more vital organs, is the endstage of initial trigger events, such as acute coronary syndrome or sepsis. The mortality is high - up to sixty percent. We have recently shown that a decrease in heart rate*

variability ([HRV], HRV variable lnVLF) can identify a subgroup of MODS with a worse prognosis. Parasympathetic stimulation can depress inflammation and might thus improve survival. The aim of the present study was to detect whether ß-blockers as mainly indirect but also direct parasympathetic modulators have a positive impact on outcome.

***Methods**. We retrospectively analysed the data of 120 consecutively admitted ICU patients with MODS. HRV was measured according to the international standards using a 24-hour-ECG. All patients were checked for ß-blocker treatment and followed up for 28-day-survival. We calculated a cutpoint (maximum of sensitivity x specificity in ROC analysis) for the HRV parameter lnVLF which predicted 28-day-survival best. The APACHE II score (APII) was calculated to characterize the severity of illness; a MODS was defined as a APII ³ 20 points.*

***Results**. The demographic data of the patients were as follows: age 59.9 ± 13 y, weight 76.6 ± 14.9, height 170.4 ± 10.0 cm, APACHE II score 26.9 ± 7.6. 56 of the 120 included patients received ß-blockers during the ICU stay. Patients with ß-blockers had a significantly higher HRV at admission than patients without ß-blockers (3.4 vs. 4.5 lnms^2, p<0.0001). Dividing the cohort of patients into four subgroups we found that patients with ß-blocker treatment and a high HRV on admission had the best survival compared with 1) patients with low HRV and ß-blocker-treatment (log rank [LR] of Kaplan-Meier-Analysis=3.9, p=0.047), 2) patient with high HRV but without ß-blockers (LR=4.6, p=0.03) and 3) patients with low HRV and without ß-blockers (LR= 13.4, p=0.0003).*

***Conclusion**. ß-blocker treatment could improve survival in MODS patients. This favourable effect might be mediated by a restoration of blunted HRV which could yield depression of the overwhelming inflammation seen in MODS.*

MEIKE BÜRKLEIN, LUTZ VOGT, ANDREAS ROSENHAGEN & WINFRIED BANZER

Cardiovascular Risk, Endurance Capacity and Heart Rate Variability in Sedentary Elderly

Summary

***Introduction**: The PROCAM (Prospective Cardiovascular Münster) scoring system is a reliable algorithm to calculate the individual 10-year risk for myocardial infarction. Associations of endurance capacity, autonomic function, and cardiac risk have not yet been investigated in depth. The present study examines the dependence of the maximum endurance capacity (VO_{2max}) and heart rate variability (HRV) on the individual risk for developing myocardial*

infarction in sedentary elderly. Methods: 11 subjects (61.3±4.8 yrs.) with a clinically relevant overall PROCAM-risk greater than 10% (Group I: 49.1±3.6 points) and 12 subjects (Group II: 55.3±8.1 yrs.) with a CHD-risk less than 10% (29.3±7.9 points) were tested for VO_{2max} using cycle ergometry. HRV time- and frequency domain parameters (RRMEAN, SDNN, RMSSD and LF, HF, TP, LF/HF, respectively) were monitored at rest. For group comparisons the nonparametric U-test was used.

***Results**: With the exception of RRMEAN (925±128 ms vs. 898±100 ms, n.s.) and the LF/HF-Ratio (2.86±2.17 vs. 2.41±1.58, n.s.) significant differences were determined for the HRV in dependence of the risk profile for the time domain indices (SDNN = 42±13 ms vs. 28±12 ms, p<.05; RMSSD = 35.82±15.51 ms vs. 22.16±11.03 ms, p<.05) and the frequency domain measures (LF = 436.75±288.86 ms^2 vs. 182.73±171.76 ms^2, p<.05; HF = 217.58±197.72 ms^2 vs. 85.55±84.12 ms^2, p<.05). Particularly for the parameters VO_{2max} (31.73±4.47 mL ´ min^{-1} ´ kg^{-1} vs. 24.36±4.15 mL ´ min^{-1} ´ kg^{-1}, p<.01) and TP (796.08± 429.73 ms^2 vs. 354.91±310.48 ms^2, p<.01) highly significant differences were obtained.*

***Conclusion**: The present findings indicate a reduced exercise capacity and impaired autonomic function in subjects with an enhanced risk for a myocardial infarction. These results underscore the predictive value of defined HRV parameters in coronary risk stratification.*

KUNO HOTTENROTT & TINA HAUBOLD

Individual Control of Physical Performance using Heart Rate Variability in Cyclists over Forty Years of Age

Summary

***Background**: Age is an important risk factor for increased cardiovascular morbidity and mortality. Hence, work load adjustment to individual fitness is of paramount importance in the training of elderly sportsmen in order to avoid potentially dangerous training modalities.*

***Objective**: To investigate the usefulness of heart rate variability (HRV) as a means of individual work load control in demanding training situations.*

***Methods**: We studied 47 ambitioned cyclists aged 40 to 47 years, who volunteered to participate in a bicycle training course for at least a week. Each participant underwent a standardized protocol which consisted of a six minute supine phase and subsequent active standing for four minutes on six consecutive days. During both protocol phases RR-intervals were recorded using a minirecorder (Polar S810i, beat-to-beat). On three days, additional plasma urea measurements were performed. HRV was quantitatively*

assessed using time domain (SDNN, rMSSD, pNN50), frequency domain (LF-power, HF-power), and Poincaré plot (SD1, SD2) indices.
***Results**: Neither training volume nor subjective perception of work load were significantly related to any of the HRV indices investigated. Plasma urea levels were also uncorrelated to training volume or subjective perception of work load.*
Discussion: Our results are in keeping with those of earlier studies, which investigated younger individuals and did not find an association between HRV and work load during training conditions. In our study, group means did not exhibit significant correlations regarding HRV indices and the above mentioned variables. However, in individual cases, HRV indices and plasma urea showed a clear relationship. Furthermore, in some individuals, we found subjective well-being to show a temporal relationship to Poincaré plot indices.
***Conclusions**: Further study is needed to clarify the role of HRV as a means of training control. Relevant confounders, such as age, sex, psycho-mental factors, and the like should be investigated to allow for a more detailed evaluation of the value of HRV in the context of training.*

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