REVIEW ARTICLE

Heart Rate Variability (HRV) for sports and exercise training

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Abstract

Athletes can improve their performance through training and recovery. To achieve their real potential, proper training load manipulation and adequate recovery are essential. Coaches and sports scientists use various methods to monitor athletes training load and recovery. However, most of the testing methods used in the fields are invasive, time-consuming and need specialised knowledge to collect and analyse data. Most importantly, these methods are not feasible to use in the field and expensive for everyday use. Heart Rate Variability (HRV) has been recognised as a reliable and non-invasive method to objectively monitor athletes during sports and exercise training that can be easily employed in the field. This article provides an overview to the heart rate variability methods and discusses its implications in monitoring athletes during sports and exercise.

Introduction

"If the pattern of the heart beat becomes as regular as the tapping of a woodpecker or the dripping of rain from the roof, the patient will be dead in 4 days" – Chinese physician Shu-he Wang (265 to 317 AD) [1]

The time difference (variation) between successive heartbeats, inter-beat intervals or R-R intervals is known simply as Heart Rate Variability (HRV). According to ChuDuc, NguyenPhan [2] *"Heart rate variability is the physiological phenomenon of variation in the time interval between heartbeats and measured by the variation in the beat-to-beat interval"*. The time between successive heart beats is never constant; there is a variation between heartbeats even when heart rate is apparently stable [3]. Heart rate variability provides essential information regarding the Autonomic Nervous System (ANS) [4-6]. The ANS is responsible for maintaining internal homeostasis that control physiological functions of the body through the actions of Sympathetic Nervous System (SNS) and Parasympathetic Nervous System (PNS) [7-10]. Sympathetic activity increases heart rate and contractility, whereas parasympathetic (vagal) activity reduces the heart rate [10, 11]. Any physiological or psychological stress will stimulate changes in the ANS that can be monitored from HRV parameters [12].

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According to the historical sources, disease diagnosis based on palpating arterial pulse (pulse diagnosis) was used firstly in traditional oriental medicine [13, 14]. In Chinese traditional medicine, pulse diagnosis method was developed between 800 and 200 BC. Chinese medical physician Bian Que (also known as Qin Yueren) described four diagnostic methods of Chinese medicine and one method was "tongue and pulse" diagnosis [13]. According to the sources, this Chinese medical physician lived about (around 500 BC), one generation before Hippocrates [13, 14].

In the history of western medicine, heart rate monitoring by palpating pulse has been first documented by a Greek medical physician and scientist call Herophilus who lived between 335 and 280 BC [13, 15, 16]. Among the western medical historians, Greek physician and scientist named Galen of Pergamon (130 to 200 AD) was famous for pulse diagnosis. He wrote more than 18 books about pulse and at least 8 books among those are describing the use of pulse measurements for diagnosis of illnesses [14, 15, 17]. He was also the first person who described the effect of exercise on the pulse. In his book "The pulse for beginners" he mentioned:

"Exercise to begin with and so long as it is practiced in moderation renders the pulse vigorous large, quick, and frequent. Large amounts of exercise, which exceed the capacity of the individual, make it small, faint, quick and extremely frequent" [18].

Research evidence has revealed HRV could be useful in recognizing healthy and diseased states

[19]. This is due to vagal mediated HRV indices which are inversely associated with risk factors related to non-communicable disease conditions [19, 20]. Recently, researchers put more attention on HRV in sports training and physical activities. Their research findings suggest using HRV as a valuable non-invasive monitoring tool for training adaptation or maladaptation and recovery [19, 21, 22]. According to previous research, non-functional over-reaching, over-training, maladaptation and insufficient recovery from last training session are indicated by reduction in vagal related indices of HRV [23-25]. Positive adaptation, functional over-reaching and recovery from previous training are indicated by increase in vagal-related indices of HRV [25-29]. Also, they reported that higher variability of heartbeat or R-R interval is related to improved quality of life [30], better physical fitness [31] and higher life expectancy [32, 33].

Heart rate variability parameters

The most commonly used HRV analysing methods are time domain (Linear), frequency domain (Linear) and Poincaré plot (Non-linear) analysis. The time-domain analysis is the simplest method and it measures the amount of variability in measurements of the period between successive normal-to-normal (NN) heartbeats [13, 34]. Frequency domain analysis also named "Power Spectral Density" (PSD) and it describes the periodic oscillations of the heart-rate signal [35]. This method decomposes the data of NN intervals into different frequency zones and quantifies them in their relative power/intensity [35]. The Poincaré plot (return map) constructed by plotting every R-R interval against the prior interval, creating a scatter plot and it is allowed to understand the patterns (visually) buried within a time series [13, 34, 36].

Table 1. Heart rate variability parameters (Makivic, B. and P. Bauer) [11]

Time-domain measures of HRV		
Variable	**Description**	**Physiological relation**
SDNN	Standard deviation of all NN intervals	Total variability
RMSSD	The square root of the mean of the sum of the squares of differences between adjacent NN intervals	Parasympathetic modulation
NN50	Number of successive RR interval pairs that differ more than 50 ms	Parasympathetic modulation
pNN50	Proportion of interval differences of successive NN intervals larger than 50 ms	Parasympathetic modulation
Frequency domain measures of HRV		
Total power	Entire power spectral area <0.40 Hz	Total variability
VLF	Very low frequency 0.003 - 0.04 Hz	
LF	Low frequency 0.04 - 0.15 Hz	Sympathetic – Parasympathetic modulation
HF	High frequency 0.15 - 0.4 Hz	Parasympathetic modulation
LF/HF	Ratio of the low to high frequency	Sympathovagal balance
Non-linear (Poincare plot) measures of HRV		
SD_1	Short term beat to beat variability	Parasympathetic modulation
SD_2	Long-term beat to beat variability	Sympathetic – Parasympathetic modulation
SD_1/SD_2	Ratio of short-term to long-term variability	Sympathovagal balance

*NN = Normal to Normal

Heart rate variability during and after exercise

When the human body is engaging in exercise or sport, critical cardiovascular adjustments take place to encounter the competing metabolic demands of the working muscles and thermoregulatory demands to control the body temperature, while maintaining blood pressure and adequate perfusion to other vital organs [37].

When starting the exercise, the "higher centre" of the brain (central command) sends descending "feed-forward" signals into the medullary cardio-vascular centre and brings the arterial baroreflex to optimal operating level. As a result, the athlete can observe a rapid increase in heart rate which is primarily mediated by reduced PNS activity known as Parasympathetic withdrawal [37]. Speedy feedback from muscle mechanoreceptors helps initial PNS withdrawal, while loading of the cardio-pulmonary baroreceptors (due to an increase in venous return secondary to muscle pump action) also elicits PNS withdrawal as well as an initial decrease in SNS activity [37].

During the entire training session or exercise time period, SNS and PNS do control the heart rate according to the intensity level of the exercise. In this time duration, SNS functions as a "tone-setter" and PNS functions as a "rapid responder and modulator". During rest and low-intensity exercise situations PNS dominates, and when the exercise intensity gradually increases, it triggers further PNS withdrawal and SNS activation. When it comes to high-intensity exercise, SNS activity dominates, [38] and during the maximal intensity systemic sympathoadrenal system will get activated [37].

When an athlete comes to the post-exercise resting situation, higher brain centre sends signals to change the arterial baroreflex to a lower level and trigger an initial heart rate decrease as a result of increase PNS activity [37]. Initial minutes of heart rate recovery (a rapid drop in heart rate) has often been attributed to "parasympathetic reactivation" [39, 40]. Some researchers suggest that SNS is also involved in this [41, 42]. As recovery continues, very slow reduction of heart rate can be observed due to increased activity of PNS and sympathetic withdrawal [37].

With the increased heart rate, differences between R-R intervals become shorter and reduce the variability of R-R intervals as a result of SNS domination [12]. Heart Rare Variability parameters like HF, RMSSD and SD1 values decrease and LF, LF / HF, SD2 values increase compared to the baseline, during and after the exercises representing PNS activities and SNS activities respectively. The balance between SNS and PNS activity depends on the intensity of the training or physical activity. Training intensity has a positive relationship with SNS activity and a negative correlation with the PNS activity.

Coaches and sports scientists need to be careful when measuring and interpreting the HRV data during exercise. The HF band parameter of frequency domain analysis is highly influenced by respiratory rate but is reliable with normal respiration [34, 35, 43].

Heart rate variability and recovery

Recovery is one of the most critical processes to the overall training program, and it is vital for improving performance. Recovery can be explained as the ability to restore body's physiological and psychological processes to their pre-fatigue state, enabling the athlete to meet or exceed past performance, when repeated, in a particular activity [44, 45]. Only if the magnitude of the physical stress level (training load) is high enough (overload principle) to evoke a reaction of the body, that the response will be relative to the stress level and, as a result, desired effects of training will be accomplished (adaptation) [12]. However, monitoring of fatigue level is essential, particularly at the microcycle level to avoid overtraining or non-functional overreaching.

There are various objective and subjective monitoring tools used to evaluate post-exercise fatigue or recovery in the field of sports. Objective tests include Maximal Oxygen Consumption (VO2max) test, Counter Movement Jump (CMJ) test, Vertical Jump Test, Creatine Kinase (CK), C-reactive protein (CRP), Cortisol, Testosterone, blood leukocyte, Myelo-peroxidase protein level and Glutathione status. Subjective tests include Recovery-Stress Questionnaire for athletes test (RESTQ-Sport) scores [46], Total Quality Recovery (TQR) [47] and Profile of Mood States Questionnaire (POMS) scores [48].

Unfortunetly, post-exercise recovery status or fatigue level monitoring methods / tests are invasive, time-consuming and need specialised knowledge to collect and analyse data. More importantly, objective tests are practically difficult to use in the field and too expensive for everyday use. Further, the accuracy of subjective tests depends on the particular subject's psychological status. With the importance of a non-invasive, comfortable, affordable and "field-use-friendly" testing method, HRV parameters is being increasingly used to evaluate the status of fatigue and level of recovery [12].

Participation in training sessions or games can lead to muscle damage, tissue inflammation, neural and metabolic fatigue, immune system depression, energy depletion and muscle soreness among athletes during the recovery period. These effects amount to physiological and psychological stress in the athlete, leading to a reduction in performance in the following hours or days, and this condition is known as "acute fatigue" [49]. Fatigue is a stressor or a stimulus to the body that produces an acute stress reaction at different physiological levels to re-organise its capacities. Consequently, the next exposure to the same stimulus will produce less fatigue, given that sufficient recovery has occurred between training sessions [50].

Some athletes expose their bodies to continuous training loads without giving adequate time duration for recovery. As a result, the body will continuously be under SNS domination during rest as well as during training sessions. Normally, when the body recovers from a previous stressor, SNS activity decreases and PNS activity starts to dominate the system [51]. Optimal recovery state is generally characterised by PNS predominance, regardless of time of the day. The time required for recovery depends primarily upon the magnitude of the initial physiological stress (training load) and psychological stress [12].

When athletes exposed to intense training sessions, the HF, RMSSD and SD1 values, which represent the parasympathetic activity of HRV gradually decrease, and during the resting period those parameters increase back to baseline values. Parameters that represent sympathetic activity such as LF, LF/HF and SD2 values demonstrate the opposite tendency. If HRV parameters unable to return to the baseline (pre-exercise) values after a reasonable time duration, this consider as a chronic disturbance in ANS, and it may occur due to overtraining [12].

Latest technology enables coaches and sports scientists to easily monitor athletes training load and recovery status using wristwatch monitors, HR belts and smartphones with technology to measure R-R intervals (HRV based portable devices). These latest devices can obtain reliable data with a minimum duration of recording of 5 minutes.

Conclusion

Importantly Heart Rate Variability (HRV) analysis can be used as a reliable, objective, non-invasive, affordable and a "field-user-friendly" testing method in sports and exercise training to plan proper training load manipulation and adequate recovery.

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