Chapter

Assessment of Autonomic Cardiac Activity in Athletes

Júlio Costa and Fábio Y. Nakamura

Abstract

Athletes, coaches, and supporting staff should assume a scientific approach to both designing and monitoring training programs. Proper load monitoring is essential to determine whether an athlete is adapting to a training program and to minimize the risk of increasing non-functional overreaching, illness, or injury. To gain an understanding of training and competition demands and their effects on the athlete, various potential physiological variables are available. Nonetheless, very few of them have robust scientific evidence to support their use. Therefore, this chapter will discuss the use of non-invasive and time-efficient methods to record and/or calculate heart rate variability (HRV) in athletes. HRV variables can provide detailed information about positive and negative adaptions over short and long periods throughout the competitive season. The accumulated knowledge regarding the importance of HRV has led both monitoring variables to become popular strategies among elite athletes, coaches, and supporting staff.

Keywords: autonomic nervous system, heart rate variability, overnight, overload, recovery

1. Introduction

Advances in technology available for monitoring athletes has led to greater opportunities to scientifically support athletes, and, thus, information regarding the modern (elite) male and female athletes are increasingly available. Over the years, numerous techniques have been used to determine the physical and physiological profiles of athletes [1–4]. Nevertheless, for some athletes and/or teams, lacking of funds can be a main cause for not including a system of training and match workload monitoring.

However, there is increasing interest in monitoring the status of the autonomic nervous system (ANS) via measures of heart rate (HR), which includes the level but mostly focuses on the variability in HR at rest [5, 6], during exercise [7–10], and following exercise [8, 9, 11, 12]. The main interest in heart rate variability (HRV) measures is that they are non-invasive, relatively low-priced, time-efficient, and can be applied routinely and simultaneously in many athletes (i.e., in individual and team sports). While the collection of HRV (beat-by-beat) was initially only possible with expensive laboratory-based electrocardiograph recorders, the recent availability of valid and portable recorders such as HR monitors [13–24], specifically-designed systems [25, 26], or smartphone applications [27] has substantially boosted the use of HRV monitoring in the field. However, despite its common implementation in the field, the usefulness of HRV indices is still a matter of debate. While the majority of studies have shown that these measures are sensitive to fitness improvements, fatigue, overload, or detraining [28–32], others have not [5].

Therefore, this chapter will discuss the use of non-invasive and time-efficient methods to record and/or calculate HRV in athletes. HRV variables can provide detailed information about positive and negative adaptions over short and long periods throughout the competitive season. The accumulated knowledge regarding the importance of HRV has led both monitoring variables to become popular strategies among elite athletes, coaches, and supporting staff. Moreover, monitoring health parameters in athletes is also crucial to understand responses to training and readiness, enabling appropriate planning. Importantly, health monitoring also intends to reduce the risk of injury, illness, and non-functional overreaching. In addition, health status data may be useful for team selection and determining which athletes are ready to sustain competition demands.

2. The autonomic cardiac activity

Cardiovascular function is regulated by the ANS [33]. The main objective of autonomic cardiovascular regulation is to control cardiac output and the distribution of blood at the central and peripheral levels. HR and the contractile properties of the myocardium, are modulated by the main components of ANS: the parasympathetic and sympathetic nervous systems [33]. The activity of these two ANS branches with opposite effects on HR causes continuous fluctuations in HR, which is called HRV [33]. The most evident fluctuations of HR are associated to respiration and result as increased HR during inspiration and decreased HR during expiration [33].

The physiological determinants of resting HRV are multiple and include cardiac muscle morphology, plasma volume, central autonomic modulation, age, and body position [34–37]. Under normal conditions, the conduction process begins in a particular area of the heart, named the atrial sinus node, whose electrical properties can generate the action potential that spreads quickly through specialized fibres to the heart, resulting in contraction of the entire cardiac muscle [38]. In addition to this intrinsic mechanism that determines the basal cardiac rhythm, the ANS plays an important role in controlling the heart function and vascular system through the sympathetic and parasympathetic fibres to the heart, and through the sympathetic fibres to the vessels [33]. The two branches of the ANS, i.e., the sympathetic and parasympathetic fibres, act in an opposite way, providing fine adjustment to the cardiac tissues in response to different stimuli and daily activities. However, an imbalance between sympathetic and parasympathetic drives has been proposed as a potential mechanism in some cardiovascular diseases such as arterial hypertension, heart failure, and myocardial infarction [39].

3. Assessment of autonomic cardiac activity

In sports, HRV might provide useful markers of positive and negative adaptations to training and competitions [5, 40]. The basic principle of HRV monitoring is to make inferences on possible changes in cardiac ANS status due to exercise while using repeated HRV measures over time. Since ANS activity is highly sensitive to environmental conditions (e.g., noise, light, temperature) [34], it is important to take some precautions so as to standardize recording conditions, in order to isolate the training-induced effects on ANS.

Precise detection of electrocardiogram (ECG) R-waves is necessary for the analysis of beat-to-beat R-R interval oscillation [33]. In fact, for practical reasons, heart period is normally measured from R-R intervals [41]. P-R interval varies normally 120–200 ms during the Holter recording but is linearly related to R-R interval in healthy subjects. P-R interval seems to be controlled by ANS and fluctuates similarly to R-R interval [41].

The analysis in the time domain further provides other related measures, including the square root of the mean of the sum of the squares of differences between successive R–R intervals (RMSSD) and the standard deviation of the R–R intervals (SDNN) [33].

In addition, R-R interval fluctuations as a function of frequency [41, 42]. Parametric autoregressive modelling and nonparametric fast Fourier transform are the most frequently used frequency domain methods generating R-R interval power spectra [41]. R-R interval power spectra are usually divided into four bands: high-frequency (HF, 0.15–0.4 Hz), low-frequency (LF, 0.04–0.15 Hz), very-low-frequency (VLF 0.0033–0.04 Hz) and ultra-low-frequency bands (< 0.0033 Hz). The spectral power densities for VLF and ultra-low-frequency power can be reliably analyzed only from long-term recordings (> 18 hours). Power spectral densities are calculated for each band, which determines the distribution R-R interval oscillation over different frequencies [41].

Moreover, HF spectral power aims to quantify respiratory sinus arrhythmia (RSA), since spontaneous respiration frequency is commonly between the frequencies of 0.15 to 0.4 Hz [41, 42]. To ensure the presence of an evident peak within the HF band and to control the effects of respiration on HF power, a standardized respiratory pattern has been used in laboratory conditions [41, 42]. Since RSA is generated by cardiac vagal nerve traffic, HF power is considered an index of cardiac vagal outflow [41, 42]. In addition, it is important to note that HF power is the most frequently used measure to quantify vagally mediated beat-to-beat R-R interval variability [41].

Furthermore, the HF component has been widely emphasized as an index that reflects the vagal modulation, whereas the LF component reflects an interaction between sympathetic and parasympathetic modulation [43]. On the other hand, experimental data suggest that the rhythm pattern of VLF is intrinsically generated by the heart and that its oscillation is modulated by sympathetic nerve endings [44]. It is important to note that circadian rhythms, core body temperature, metabolism, hormones, and intrinsic rhythms generated by the heart all contribute to lower frequency rhythms [i.e., VLF) [38]. Moreover, long-term regulation mechanisms and ANS activity related to thermoregulation, the renin-angiotensin system, and other hormonal factors may contribute to this band [45, 46]. For instance, lower power in this band has been associated with high inflammation in a number of studies [47, 48] and has been correlated with low levels of testosterone, while higher VLF power that occurs during the night and peaks before waking have been associated with other stress biochemical markers, such as cortisol [49, 50]. In fact, authors [49] suggest that increased autonomic activity (i.e., higher VLF power) may correlate with the morning cortisol peak.

Although the ratio between LF and HF (LF/HF) has been used historically as a measure involving the sympathetic/parasympathetic balance [51], recent studies suggest that this measure cannot be used as an accurate measure of this balance [42].

4. Suggested methods for the assessment of autonomic cardiac activity

Assessment of the HRV from linear methods can be executed from records with durations of 2, 5, and 15 minutes (short-time), and over 24-hours (long-time) [18, 33]. Vagal indices of HRV, such as the logarithm RMSSD (lnRMSSD), reflecting cardiac parasympathetic modulation, are sensitive to fatigue and have been practical in evaluating individual training adaptation in team sports athletes [52, 53]. Moreover, the weekly (across 4–7 days) coefficient of variation (CV) of lnRMSSD ($lnRMSSD_{CV}$) may provide valuable information concerning training-induced perturbations in homeostasis, i.e., can reflect the day-to-day variations in cardiac parasympathetic activity [52, 54]. In general, athletes with a lower $lnRMSSD_{CV}$ present higher aerobic fitness and seem to cope better with training and match loads [55–57]. In fact, higher $lnRMSSD_{CV}$ associated with reduced average lnRMSSD during training and matches may be interpreted as a sign of overload.

Recordings of at least 2 minutes are adequate for most HRV analyses quantifying the short-term fluctuation of R-R intervals, but 5 minutes is preferable [41]. The reproducibility of short-term HRV analysis has been assessed in several ways and noted to be relatively good if measurement is highly controlled [41]. Both respiration frequency and tidal volumes affect respiratory-related R-R interval fluctuation [41]. A higher breathing rate leads to minor RSA, as a higher tidal volume increases RSA. Diurnal variation of R-R interval fluctuation [41] and a previous meal also influence short-term HRV measurements [41]. Furthermore, laboratory conditions involve some sensitive psychosomatic factors, which appear to influence the measurements [41].

The assessment of long-term 24-hour ambulatory R-R interval oscillations has been introduced as a method for the quantification of cardiac autonomic modulation [18]. The finding of an association between 24-hour HRV and mortality among patients with recent myocardial infarction increased the use of ambulatory recording for the assessment of cardiac autonomic tone [18]. The analysis of 24-hour HRV has high reproducibility with no placebo effect, and it is not dependent on the subject's cooperation [41]. The main limitation of 24-hour ambulatory R-R interval recordings is normally the uncontrolled daily activity and respiration. Despite the good reproducibility of 24-h recording., the individual differences in daily activity and respiration pattern may limit the analysis of ambulatory HRV in cross-sectional studies [18].

The presence of noise, trends, ectopic beats, and artefacts has been considered as the main problem found in records of HRV. These issues can directly affect the quality of HRV analysis, requiring signal correction [58]. Therefore, ectopic beats are, in general, automatically removed and replaced with interpolated adjacent R–R interval values using a low filter [59]. In addition, to reduce any potential non-uniformity or skewness in HRV, data can be log-transformed by taking the natural logarithm [60] before conducting any statistical analyses [31].

It is also important to note that monitoring training-related cardiac autonomic responses has been facilitated by using after-waking ultra-short-term HRV measurements in male and female athletes [61–63]. However, this method does not allow evaluation of the time course of post-exercise quantification of HRV during periods of more steady physiological states [55, 64]. Thus, HRV recordings conducted during night sleep could be an interesting substitute.

HRV data collected during selected slow-wave sleep episodes (SWSE; defined as deep stage of sleep), which offers great signal stability and high standardization of both environmental factors and respiratory influences on HRV, might be preferred [65, 66]. Nevertheless, night recordings could be difficult to implement daily [63], limiting their usefulness. Throughout the SWSE method, it was possible to observed that a single session of supramaximal intermittent exercise triggered a decrease in vagally-mediated HRV indices in young non-athletes during sleep following exercise [64]. Importantly, the SWSE requires the analysis of 10 min out of many hours of sleep.

The SWSE considers the following steps:

1. the first 10 min of the first low and regular HR episode lasting at least 15 min;

2. the lowest SDNN throughout the period of interest;

3. a circular Poincaré plot (i.e., a round cluster of points in R–R intervals plotted as a function of the previous one);

4. a low inter-beat autocorrelation between successive R–R intervals (i.e., correlation coefficient of the Poincaré plot <0.5).

In contrast, has been proposed the analyses of overnight sleep cardiac autonomic activity using an "hour-by-hour" approach using all the R–R intervals recorded throughout the sleep period [67]. The authors found that vigorous late-night exercise did not disturb sleep quality in physically active male subjects [67].

5. Conclusions

Overall, monitoring HRV in athletes can be useful for early detection and intervention before significant performance and health decrements are observed. Non-invasive and time-efficient methods/equipment such as wearable beat-to-beat HR monitors can provide detailed information about positive and negative adaptions over short and long periods throughout the competitive season. In addition, each athlete could perform the recordings at home, adopting a "real world scenario" to grant high ecological validity to the research and/or practical interventions. The accumulated knowledge regarding the importance of HRV has led HRV monitoring to become a popular strategy among elite athletes, coaches, and supporting staff.

Conflict of interest

The authors declare no conflict of interest.

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