IOSR Journal of Sports and Physical Education (IOSR-JSPE)
e-ISSN: 2347-6737, p-ISSN: 2347-6745, Volume 10, Issue 3, (May. – June. 2023), PP 29-34
www.iosrjournals.org

Heart Variability And Competitive Training - Concepts For Using The Tool In The Control And Prescription Of Training

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Abstract
Several conditioning programs aim to combine strength training and aerobic training to promote metabolic adaptations and improve both health and sports performance. There is a lot of debate in the literature regarding the competition between these stimuli, but it has been found that the interference is dependent on the intensity and volume of the training. Therefore, tools that can quantify the physiological stress imposed on the body by exercise and respond to changes in training variables can provide valuable insights for prescribing and monitoring concurrent training. One such tool is heart rate variability (HRV), which has proven to be an interesting and responsive measure for various factors that affect performance during training sessions. By analyzing certain indices derived from HRV, it is possible to quantify the dominance of the autonomic nervous system's response to the applied stimuli. Considering these aspects, this study aims to present important concepts and suggest the use of HRV as a means to control training sessions in a combined exercise program.
Key-words: *Exercise, conditioning, health.*

Date of Submission: 29-05-2023 Date of Acceptance: 09-06-2023

I. Introduction

Concurrent training is characterized by the practice of aerobic and strength exercises within the same exercise program, aiming to promote metabolic adaptations that enhance both health and sports performance. Recent guidelines from ACSM recommend the inclusion of both types of exercise in a weekly program for the improvement of health and quality of life (ACSM, 2013). In the context of enhancing sports performance, this combination is widely applied to improve athletes' performance (GARCIA-PALLAREZ and IZQUIERDO, 2017). However, due to the different metabolic pathways involved, some studies indicate that endurance training may interfere with strength development and muscle hypertrophy when compared to isolated strength training (COFFEY and HAWLLEY, 2007; LUNDBERG et al., 2012; COFFEY et al., 2009b; Mounir et al., 2009; STEPTO et al., 2009; BAAR, 2014). However, other research suggests that these interferences are dependent on the volume, intensity, frequency, and rest between training sessions (APRÓ et al., 2013; PUGH et al., 2015).

The most important discussion revolves not around the combination itself, but rather on how the sessions can be distributed to achieve an appropriate alignment between the timing and order of efforts, ensuring that training is effective and interference between the two stimuli is minimized. This allows for greater gains in strength, muscle mass, and cardiorespiratory fitness, which are essential components for improving performance and health (WOJTASZEWSKI et al., 2000; Wang et al., 2011; ROBINEAU et al., 2016).

After the completion of an exercise session, adjustments need to occur during the recovery period to respond to the stimulus provided. This stimulus is often interpreted as stress, temporarily disrupting the body's homeostasis and requiring specific responses from the body's systems, including the cardiovascular system. Some of these changes provide information on when the cardiovascular system has recovered for the next training session (Romero, Minson, and Halliwill, 2017). Similarly to the cardiovascular system, the autonomic nervous system (ANS) is highly responsive to stressful situations, including exercise (Fu and Levine, 2013). In this regard, heart rate variability (HRV) has gained attention for analyzing changes caused by stressful situations on the body, which demand adjustments in the cardiovascular system through the analysis of ANS activity via heart rate fluctuations. One of its applications is the control of training loads based on this indicator, which stands out for enhancing athletes' performance guided by this model (Makvic et al., 2013). Considering these perspectives, the present study aims to provide information and suggest the use of HRV for prescribing workloads and defining variables (volume, intensity, and frequency) during the implementation of a concurrent training program, taking into account its sensitivity to detect various stress situations that can influence performance in training sessions, thereby allowing for more precise adjustments to the current state of the practitioner.

II. Methods

A search was conducted in the PUBMED database from February 15, 2023, to May 22, 2023, using the following keywords: heart rate variability and resistance training, heart rate variability and exercise, heart rate variability and endurance, and heart rate variability and concurrent training. The search yielded 547 articles, which were then narrowed down based on their titles, resulting in 138 articles selected for abstract reading. After this stage, 51 articles were chosen for full-text reading, of which 30 were included to support the initial review. Upon reading, relevant references were identified and added to the text.

III. Physiological characteristics and overview of HRV

The measurement of heart rate variability (HRV) has been characterized as a non-invasive method to assess the activity of the autonomic nervous system (ANS) through heartbeats (PADULO et al., 2013). The relationship between HRV and physical activity can be analyzed through the adjustments that the ANS exerts on the cardiovascular system in response to exercise-induced demands on the cardiac muscle (VATNER, 1976; FAGARD, 1992). The ANS functions in the heart through the innervation of its two branches, the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS), which are responsible for regulating heart rate. Therefore, the balance between these systems can be demonstrated through heartbeats (Marques et al., 2009; Makvic et al., 2013).

Specifically, the right vagus nerve innervates the sinoatrial node, while the left vagus nerve innervates the atrioventricular node. The atria are also innervated by efferent vagal pathways, while the myocardium is sparsely innervated by vagal nerves. Regarding sympathetic efferent nerves, they are present throughout the atria, particularly in the sinoatrial node and ventricles (VANDERLEI et al., 2008; WHOOLEY et al., 2008).

The SNS stimulates cardiac contractility and conductivity, while the PNS has opposing effects and promotes relaxation. The activities of the SNS are mediated through adrenergic receptors (alpha and beta), while the effects of the PNS are related to muscarinic receptors (AUBERT, SEPS, & BECKERS F., 2003).

The regulation of the ANS on heart rate involves complex mechanisms, particularly the solitary tract in the medulla, which receives sensory inputs and stimulates responses in certain situations (Makvic et al., 2013). One of the main functions of this system is to maintain physiological homeostasis.

Exercise, emotions, stress, and changes in blood pressure are some of the situations that can interfere with this balance and generate adaptive responses from the ANS (RIBEIRO & MORAES FILHO, 2005).

To detect autonomic responses through HRV, variations in consecutive time intervals between the peaks of the QRS complex (a graphical representation of ventricular polarization and depolarization) are measured. These intervals, known as R-R intervals, can be collected using electrocardiograms and pulse rate monitors, and then analyzed using specific computer software (QUINTANA, HEATHERS, KEMP 2012; VANDERLEI et al., 2008; MAKVIC et al., 2013).

The analysis of ANS activity can be performed in various ways, with the most common approaches being frequency domain analysis and time domain analysis. The frequency domain describes high-frequency (HFC) and low-frequency (LF) rates, which serve as indicators of activities from different parts of the ANS (Task Force Of The European Society of Cardiology et al., 1996). By analyzing frequency differences in HRV, it is possible to distinguish sympathetic and parasympathetic activities on the heart (Acharya et al., 2007; Makvic et al., 2013).

LF (0.04-0.15 Hz) during intervals between heartbeats represents sympathetic activity, while HFC (0.15-0.4 Hz) represents parasympathetic activity (VANDERLEI et al., 2009).

For the analysis in the time domain, the standard deviations (SD) of all recorded RR intervals within a time interval are observed (SDNN). SDANN represents the SD of the average normal RR intervals obtained every 5 minutes within a specific time interval. The average SD of the RR intervals within normal limits over a

5-minute period represents SDNNi. When analyzing the records of SDNN, SDANN, and SDNNi, it is not possible to distinguish whether the observed alterations are due to an increase in sympathetic nervous system (SNS) activity or a decrease in parasympathetic nervous system (PNS) activity (RIBEIRO et al., 2005; PUMPLR et al., 2002).

A more distinguishing analysis in the time domain is achieved through the percentage of adjacent RR intervals that have a duration difference greater than 50 ms (pNN50) and the square root of the mean of the squared differences between adjacent normal intervals within a time interval (rMSSD) (Bittencourt et al., 2005; Novais et al., 2004; Makvic et al., 2013). The indices measured in the rMSSD and pNN50 domains indicate the predominance of PNS activity (RIBEIRO et al., 2005).

There are other evaluation methods, such as geometric (Poincaré) and nonlinear approaches. However, the data presented here provide information on how it is possible to distinguish the predominant activity of the autonomic nervous system through VFC analysis. For further information on the analyses, refer to (Task Force Of The European Society Of Cardiology et al., 1996; Ribeiro et al., 2005; Vanderlei et al., 2009; and Makvic et al., 2013).

IV. HRV in training load control

A relatively new area of research involves monitoring exercise loads through HRV analysis, aiming to adjust workloads based on the autonomic responses analyzed in the aforementioned domains (MAKVIC et al., 2013). Utilizing HRV as a tool for this purpose is appealing due to its simplicity in measuring recovery and fatigue, thereby ensuring optimal performance in activities with varying stimuli and intensities, such as concurrent training (SANDERCOCK and BRODIE, 2006; NAKAMURA et al., 2015).

Increases or decreases in HRV can indicate positive or negative responses in athletes and practitioners due to the significant role of the autonomic nervous system (ANS) in adaptive responses (PLEWS et al., 2013). Monitoring training loads through HRV analysis provides a measure of adaptive response (HAUTALA, KIVINIEMI, and TULPPO, 2015).

Studies suggest that after excessive workload overload or negative adaptation to training, a concurrent decrease in parasympathetic activity of the ANS can be observed, which can be detected through HRV measurements (HYNYNEN et al., 2006; BOSQUET et al., 2008; MAKVIC et al., 2013).

Electrocardiogram (ECG) and portable heart rate monitors have proven to be efficient for such analyses, with the latter being particularly attractive as a simplified tool for monitoring training loads (FLATT and ESCO, 2015a).

The initially recommended period for HRV assessment consists of 10 minutes, with the first 5 minutes representing the stabilization period and the subsequent 5 minutes representing the post-stabilization period (NAKAMURA et al., 2015). Esco and Flatt (2014) suggest a shorter post-stabilization period (around 1 minute), which yields the same results as the 10-minute protocol, demonstrating the time optimization provided by HRV measurement and enabling the evaluation of a greater number of athletes and practitioners in a single day for daily control, as the second data collection model can be completed in 2 minutes.

HRV indices have also proven effective in assessing the effects of repeated sprint training, indicating sensitivity to detect changes in the homeostatic balance that occur during intense activities (SOARES CALDEIRA et al., 2014). Recently, some authors have suggested that these measurements can be performed multiple times during the week, providing appropriate responses regarding the physiological responses resulting from imposed training loads (FLATT and ESCO, 2015b; PLEWS et al., 2012; 2014).

V. HRV and exercise - considerations for concurrent training

Despite some molecular mechanisms, such as mammalian target of rapamycin complex 1 (mTORC1) and adenosine monophosphate-activated protein kinase (AMPK), acting in an antagonistic manner, where the former stimulates protein synthesis while the latter seems to impair this signaling, concurrent training can be applied to elicit favorable adaptive responses in both stimuli, namely, maximizing strength and muscle mass gains and increasing cardiorespiratory fitness (BAAR, 2014; ROBINEAU, 2016; WOJTASZEWSKI et al., 2000; ISSURIN, 2010).

To utilize HRV in load control, it is necessary to understand the specific autonomic activity response to each training protocol, which can vary according to individuals' training level (SEILER, HAUGEN, and KUFFEL, 2007). Some studies that employed HRV and analyzed its domains aimed to quantify fatigue and stress levels to guide sessions and assess the relationship between ANS activity data and subsequent session or test performance.

In Kiviniemi et al.'s study (2010), athletes who had their endurance training prescribed based on HRV were able to maintain higher workloads and achieve better performance compared to athletes using a pre-defined prescription.

Teixeira et al. (2011) evaluated autonomic activity after three types of training: aerobic training only (30 minutes at 75% of peak VO2), resistance training only (6 exercises with 20 repetitions at 50% of 1RM), and concurrent training (aerobic training followed by resistance training). The analysis of HRV domains indicated a longer delay in the restoration of basal vagal activity after the combined training, suggesting a more stressful situation for the body, which would require longer rest periods between sessions if following the study's protocols.

Regarding strength training, specifically weightlifting, Chen et al. (2011) sought to assess whether the restoration of parasympathetic activity (measured through HRV) would coincide with the point of performance improvement during lifting. For this purpose, a training protocol with approximately 2 hours of progressive load training and execution of 4 exercises was applied, and HRV measurements were taken 3, 24, 48, and 72 hours after training for domain analysis. The researchers found a decreased high-frequency (HF) component for up to 48 hours, which returned to baseline levels after 72 hours. This restoration of vagal tone coincided with the participants' performance improvement in the assessed strength parameters. These findings suggest that a significant rest period should be respected after an intense weightlifting session before another stimulus is provided.

Kingsley and Figueroa (2016) demonstrated that sympathetic activity increased after an acute session of resistance training in a whole-body protocol. This increase may be due to plasma volume expansion, metabolite accumulation, catecholamine release, extensive recruitment of muscle fibers, and high energy demand, which characterize a state of significant physiological stress. Considering this information, after a resistance training session involving a wide range of muscle groups, a longer recovery time may be necessary for vagal activity restoration.

As mentioned above, some studies have utilized HRV (Heart Rate Variability) for training load monitoring and prescription based on autonomic activity. However, few studies have examined the use of HRV as a marker for analysis during concurrent training, such as the study by Panissa et al. (2016). In this study, it was found that a decrease in HRV leads to a decrease in strength caused by the workload of high-intensity interval training. However, the authors highlight that individuals with good aerobic conditioning exhibit faster recovery of autonomic activity after concurrent training within the same day.

A model for using HRV in the control of training loads during concurrent training is exemplified in

Figure 1.

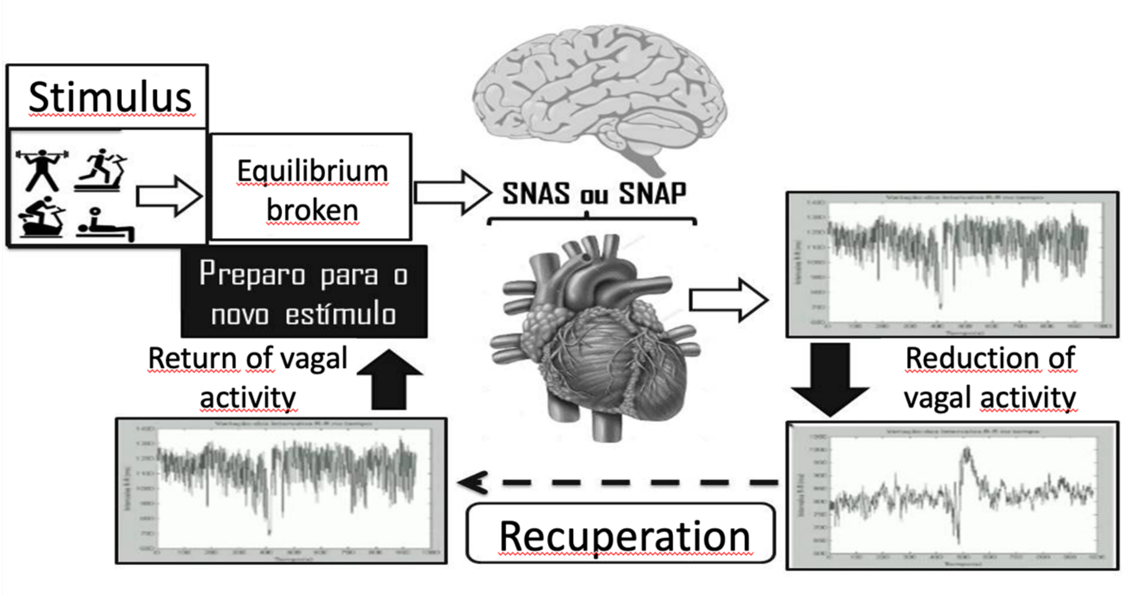

Figure 1 - Proposed model for monitoring training loads using HRV. Prior to the first stimulus, HRV measurement and analysis are conducted following the procedures proposed in the literature. After the first stimulus (strength, aerobic, or both), a disruption of body equilibrium is observed, accompanied by a reduction in vagal activity indicating the physiological perception of the imposed stress. During the recovery period, a new measurement is performed to assess whether vagal activity has returned to baseline levels. Based on the data obtained from the analysis, the intensity and volume of the training load for the subsequent session are programmed. By following this adaptable model, the aim is to minimize interference between the stimuli.

VI. Conclusion and Future Perspectives

The use of HRV has proven to be useful for monitoring, prescribing, defining workloads, and adjusting training intensity in endurance and resistance training practitioners, where information about sympathovagal balance can help improve performance and consequently enhance adaptations in conditioning programs. Considering that traditional models of periodization with pre-defined training loads, although successfully used in various situations, are currently being questioned due to their rigidity and lack of flexibility considering the current state of the practitioner/athlete, this type of tool that provides real-time information can be interesting to address some of the gaps and concerns raised recently.

Compared to other techniques and markers for training prescription and periodization, HRV represents a relatively new field in research. Given the ease of its application and data analysis, it is expected that new studies will utilize this instrument to assess adaptations and performance in training, enabling more precise prescription methods.

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