E-ISSN:2319-3050

Research Article

Exercise Physiology

International Journal of Research Padagogy and Technology in Education and Movement Sciences

2023 Volume 12 Number 02 APR-JUN

Publisher

Research & Academic Publishing

www.theuniversityacademics.com

APPLICABILITY OF HEART RATE VARIABILITY AS A CARDIAC-AUTONOMIC MARKER IN EXERCISE AND SPORTS SCIENCE

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DOI: https://doi.org/10.55968/ijems.v12i02.381

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Beat-to-beat variations in heart rate (HR) or variations in consecutive R-R intervals are usually described to be Heart Rate Variability (HRV). With the passage of time Heart Rate Variability comes out as an important clinical and investigational tool to provide insight into autonomous nervous tone. It is in point of fact that a wide variety of research works are being conducted on HRV. The present study presented an essence of the applicability of HRV in Exercise and Sports Science research. Available literatures which rendered and fulfilled the primary objective of this article were taken into consideration and reviewed and presented them systematically and interpreted with critical observations. The autonomic nervous system (ANS) regulates the cardio-vascular system with its neural control through the sympathetic & parasympathetic pathways. Analysis of HRV allows insight in this control mechanism. It can smoothly be detected from electrocardiogram (ECG) recordings, causing time series (R-R intervals) which are generally examined in time and frequency domains. Consequently, the HRV to be an important clinical and investigational tool is suggested to establish the role of exercise for wholesome betterment of athletes and practitioners.

Keywords: Exercise, HRV, Sports Science, Cardiac-autonomic marker, Heart rate, ANS

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Sridip Chatterjee, Associate Professor, Department of Physical Education, Jadavpur University, Kolkata, West Bengal, India. Email: sridipchatterjee.ped@jadavpuruniversity.in	Dilip Roy Roy, Sridip Chatterjee, APPLICABILITY OF HEART RATE VARIABILITY AS A CARDIAC-AUTONOMIC MARKER IN EXERCISE AND SPORTS SCIENCE. IJEMS. 2023;12(02):282-289. Available From https://ijems.net/index.php/ijem/article/view/381	

Manuscript Received	Review Round 1	Review Round 2	Review Round 3	Accepted
2023-04-11	2023-05-17	2023-05-24	2023-06-22	2023-08-13
Conflict of Interest	**Funding**	**Ethical Approval**	**Plagiarism X-checker**	**Note**
NIL	NO	YES	13	

Introduction

As a specialized pump, the heart delivers blood throughout the body with the help of its regular and constant contractions (1).Its pumping actions is happened due to a streaming of electricity across the heart which results in heart beats in a cyclic order. In a simple way, heart rate (HR) is the speed of the heart beats estimated by the number of contractions per unit of time (2).

In exercise and sports field, physiological markers in individuals get huge attention as soon as the researchers have found that they correlate with the performance of an individual. Traditionally, alterations in individual resting heart rate(RHR), has been nowadays utilized as an indication of physiological condition and also to dig up fatigue in athletes as it is an important and easily measurable marker(3).

Heart rate variability (HRV) has recently stood to be an approved and well-known marker. It (HRV) is the interval in time between successive heartbeats and signifies as an important marker for health, fitness, recovery, and cognitive activities (4,5,6). HRV functions may give an indication of autonomic nervous system's (ANS) status. There is supporting evidence across tasks and populations that higher resting- state HR, compared to the individual baseline, is connected with increased performance in tasks that demand executive functions [active attention and working memory] (7),on the other hand a lowered HRV compared to individual baseline can mean poor health and decreased performance(6). HRV can also be justified as a tool to supervise training program and to keep an eye on recovery and performance too (8).

Research has unveiled that HRV is an effective tool to observe changes happened in fitness and recovery as well as program training in endurance athletes while measured during rest over several weeks or months(5,8, 9,10).

HRV measurements and its beginning

Stephen Hales noticed alteration in arterial pressure as well as in beat-to-beat time period at the time of respiratory cycle in horses in 1733. But for the first time documented report on variability and cardiac rhythms has certainly been credited to Carl Ludwig. He reported respiratory sinus arrhythmia (RSA) in 1847 with the help of a smoked drum Kymograph, an instrument he cooked up which allowed him to measure mechanical activity. Applying galvanometers during the early twentieth century, William Einthoven made for a first time continuous recordings about an electrical function regarding the heart (11, 12). In the beginning of 1960s, Norman Jeff Holter produced a tiny portable device which was able to record long-term ambulatory ECGs (>24 hrs.) (12).The device led to an exponential growth in information about the link between HRV and diseases.

History speaks that HRV was studied first during the 1960s in clinical research settings of the fetal distress and at the time of 1970s (12) the correlation in the middle of decreased HRV and greater mortality risk after myocardial necrosis, was established. Nowadays, not only in clinical use, HRV is obtaining momentum in exercise and sports science too.

Based on these initial ECG measurements time domain analysis has been carried out and eventually frequency domain analysis came forwarded during the early 1970s (13).The quest for HRV in context of monitoring performance related to physical and sports activities, is comparatively a new field. It helps to diagnose changes, happened in the autonomic nervous system with regards to exercise to monitor the training status, fatigue and recovery, competition readiness and stress coping.

This has been accessible because of modern computerized devices and different types of on-line applications which are invariably improved and consistently customized in order to produce more detailed information regarding the athletes' physiological responses to training stimuli. The heart beats do not maintain the uniformity of a clock (13).Variations in heart rate are usual and it indicates the heart's capability to counter to different stimuli, including breathing, mental stress, hemodynamic changes, pathological conditions and physical exercises (14, 2, 15).Therefore the intervals in time between successive heart beats are related to the autonomic nervous system's influence on the sinus node of the heart. Henceforth, HRV as a non-invasive measurement tool is being recommended for analyzing the ANS condition in different categories of populations, including all-level athletes.

Methods and materials

An attempt has been made to search literatures regarding Heart Rate Variability (HRV) which encompasses exercise and sports by using The Pub Med, Google Scholar databases. Search term, 'heart rate variability' was utilized in conjunctions with 'exercise/training' or 'sports'. The search was restricted to the literatures which were only in English Language. Abstracts were introspected and articles individually favored for further review based upon the merits and focus of the study. For good measure, the reference lists of the pertinent articles were quested for more apt studies. While there were several references for a single one, the most apt paper was considered.

Findings

Heart rate variability, an electrophysiological marker

With the passage of time HRV is used to quantify physiological responses to training/exercise. The improvement in resolution of commercial pulse sensors has made analysis of an electrophysiological marker, HRV more accessible (16) and monitoring the ANS via HRV has become non-invasive and comprehensive as well as cheap. Monitoring of HRV allows athletes to make inferences from repeated HRV measures over time. It enables reasoning about why HRV changes, how it changes with different training stimulus, and how performance changes in relation to HRV. Athletes' individual responses to training can be monitored in order to adjust training load and programme.

Figure 01: Schematic Diagram showing heart rate control mechanism.

Enclosed as Annexure 01

In a very simple way, HRV is the product of the ANS (7). It is universally recognized that the ANS has two wings - the sympathetic branch, which is connected with mobilization of energy for hard tasks, and the parasympathetic wing, which is accountable for vegetative functions, i.e., non-conscious activities to conserve the body alive. Both these wings aid in regulating the heart and circulation. The sympathetic branch increases heart rate and the parasympathetic branch slows it down (14).These branches maintain equilibrium(6)(See figure-1).Variations in the outcome of these two wings result in heart rate variability(HRV).However, while this dynamic balance relocates to favor the Sympathetic wing, heart beats become less variable. Thus, a high HRV designates high ANS responsiveness while a low HRV indicates low ANS responsiveness. A continued and lowered HRV comparison to baseline can imply poor health and decreased performance (6).A lower HRV has also been associated to worse cognitive performance in case of memory, language, attention, executive functions, as well as visuospatial skills, and processing speed (4).HRV has also been found to be related to reaction time specifically as the higher HRV is correlated with faster reaction times (17, 7). HRV varies with circadian rhythm (18) and internal or external aspects such as stress or training (19, 5).There is a downturn in HRV with age, and males usually have a moderately higher HRV than females (20).

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Measurements of HRV

Fluctuations in heart rate variability can be estimated applying time domain, frequency domain, and nonlinear measures. These atypical measures demonstrate changes in unlike aspects of the underlying neural control of the heart. The Task Force of the European Society of Cardiology and the North America Society of Pacing and Electrophysiology have published a comprehensive guideline document on the measurement & interpretation regarding HRV (21).

Time domain measures

Universally used time domain variables incorporate the standard deviation of the NN interval or normal to normal RR interval (SDNN), the standard deviation of the average NN interval (SDANN), root mean square of the successive differences of the RR interval (RMSSD), the number of successive NN intervals which have a difference of >50 ms (NN50), and the NN50 as a proportion of the total number of NN intervals (pNN50). The SDNN demonstrates all cyclic elements playing a part in the variability at the time of recording and is mathematically equal to the total spectral power. As the length of recording reduces, SDNN shows higher frequencies. The SDANN is assessed in short periods, generally periods of 5 minutes during a 24-hour recording. It produces an estimate of longer cycles in HRV (21).

The RMSSD demonstrates the variability in the change in NN interval. High-frequency oscillations promoteNN to change faster, causing greater changes in RMSSD, while on the contrary low frequency fluctuations contribute to slower changes in NN and thus less change in RMSSD. Therefore, though RMSSD is influenced by all fluctuations at all frequencies, (22) higher frequencies have a stronger impact. That is why many studies have demonstrated a high correlation between RMSSD and high-frequency power in the cardiac spectrogram, and recommended that RMSSD is a fine sign of cardiac vagal control (21, 11). However, as RMSSD shows all frequencies, it may also demonstrate sympathetic impact (22)and for that reason it may not represent as a solid index of vagal cardiac control. The fact that RMSSD is barely sensitive to alterations in respiratory patterns, (23) it is steadier to compare data at similar respiratory frequencies. Both the NN50 and the pNN50 correlate strongly with high-frequency cardiac spectral power (21).

Frequency domain measures

The power spectral density of HRV in short-term recordings (2–5 minutes) comprises of very-low-frequency (VLF ;< 0.04 Hz), low-frequency (LF; 0.04 to 0.15 Hz), and high-frequency (HF; 0.15 to 0.4 Hz) oscillations. The total frequency signifies the sum of all these three frequencies. Even though VLF turns up to be connected to the mastery of temperature and vascular tone, (21,24,25)it is also influenced by the rennin- angiotensin-aldosterone system,(26)and both sympathetic(11)and parasympathetic(26)impacts have been recorded. Although some literatures do measure of VLF, the electrophysiological clarification is not well equipped (27) and so VLF is, in general not shed light on (21).So, the two main frequency bands in short-term recordings incorporate the LF and HF bands. The HF is usually implied as respiratory frequency, as the peak frequency in this band falls out at the same frequency as respiratory frequency (11).Analysis of the spectral power of an entire 24-hour recording also incorporates VLF (in this case,0.003–0.04 Hz) and ultra -low frequency (≤ 0.003 Hz).

Nonlinear measures

Heart is usually under authority of a complex reciprocity of hormonal & neurological inputs(28,29).These inputs usually contribute to a chaotic pattern of HRV(30) linear methods of analysis are not capable to adequately model it(28,31).Methods of analysis stemmed from nonlinear dynamics which impart a more precise expression of the complexity and order of the RR interval(28,29,32,33).Four nonlinear methods have been figured out: (1)fractal measures together with power-law correlation, detrended fluctuation analysis, and multifractal analysis; (2) entropy measures incorporating approximate entropy/sample entropy, multi-scale entropy, and compression entropy; (3) symbolic dynamics measures; and (4) Poincaré plot representation. Although detrended fluctuation analysis, multiscale entropy analysis, and symbolic dynamics have been expressed as a fruitful tools for risk stratification and detectingof cardiovascular disease, other measures demonstrate promise but still need to be authenticated (28).

A comprehensive narration of these measures and their hindrances is complicated and beyond the reach of this review. In this regard further information can be available in reviews

By Voss et al., (28), Routledge et al.,(34) and Kleiger et al.,(32).

HRV and training adaptation

Kiviniemi et al.,(8) studied the viability of applying HRV in daily training scheduling for runners. In the course of four weeks, one group met with a preplanned training program, when the other group’s training was fixed onchanges in HRV measures each morning. The HRV-led group had notably higher up gradation in both peak oxygenconsumptions and maximal running velocity after four weeks, guiding the authors to come to an end that HRV-led training is constructive for polishing up cardio respiratory fitness.

An indistinguishable impact was also examined by Da Silva et al,. (9) in female untrained runners. One group executed training, guided by HRV and on the contrary a control group went after a standardized schedule. The HRV-led group enhanced their time on five kilo-meters of running to a greater extent than the control group, and also upgraded their HRV at rest.

Javaloyes et al,.(35)set, side by side the efficacy of HRV-led training and block periodization training in-particular and between two groups of cyclists. The training period continued for eight weeks with an extra three-week assessment phase before and after the training phase. The calculated fitness and performance has been similar between the groups, but it was come to terms on that the HRV-led training could results in far better in case of training outcome. It was recorded that the evidence offered additional support to the view that HRV stands as a relevant electrophysiological tool to dig up daily recovery and fatigue, and eventually endorses training.

HRV to be a performance predictor

In an attempt to predict performance from HRV, Di Fronso et al,. (36) looked into an ally of HRV and performance of seven players in a basketball team with seven weeks period. HRV has been estimated in the morning of each match day. Results of regression analysis demonstrated that an HRV index reckoned for 15% of the variance in performance (R2 = 0.15), recommending that HRV could be affirmatively connected to performance. Higher levels of HRV at the time of morning were related with higher performance during the game.

Likewise Peterson (37) monitored HRV of 15 male track and field athletes to speculate sprint performance. HRV has been monitored 24 hours prior to competitions, and each participant reported 12 competitions, leading to 182 samples in total. Individual performance was foreseen applying machine learning ensembles with an accuracy of up to 85.6 ± 4.8%. The practical implementation of such predictive models has been accentuated as a tool to foresee competitive performance, and replicate athletic performance under various physiological conditions. This may be of service to coaches and athletes to plan for training sessions and competitions.

Pojman et al,.(38)procured physiological measurements of 10 expert and 30 novice shooters at the time of simulatedshooting to anticipate shooting expertise. The experts set forth more regularity and better perfection across shooting tasks. They also reported greater HRV in the time of cognitive activities compared to the novices. Feasibly, novices had more sympathetic activation as a consequence of anxiety and mental stress.

In the same area, Ortega and Wang (39) observed HRV, self-efficacy, and application of mental skills in both experts and novices prior to shooting performance. They noted that HRV had a significant positive correlation with self-efficacy as well as shooting performance. Novice shooters put on view the highest heart rate and lowest HRV before shooting, which was recorded, could have been ascribed to anxiety. Novices were found with the lowest self- efficacy. They went into that physiological condition as measured by HRV may have more effect on novice shooters than advanced shooters, which is implied the findings by Pojman et al,. (38).

Conclusion

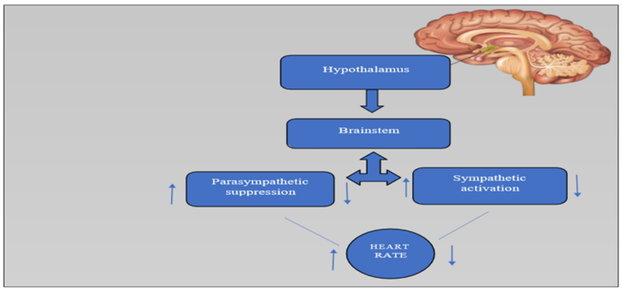
HRV has now been an important electrophysiological marker which reflects the controlling mechanism of involuntary physiological activity by the ANS with the help of its two distinct wings i.e., sympathetic &parasympathetic nervous system and henceforth it implies the fitness status of athletes and general populations who go for exercises. As HRV measures do not put all the aspects of wellness and performance of an athlete or individual in the picture (40, 41), its collaborative application with some other useful psychometric & non-invasive

Performance indicators can impart a more fruitful way out for guiding training session for an athlete (42, 43).Finally, the HRV to be an important clinical and investigational tool is suggested to establish the role of exercise for wholesome betterment of athletes and practitioners.

Annexure

Annexure 01

Figure 01: Schematic Diagram showing heart rate control mechanism.



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