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ORIGINAL ARTICLE

Estimation of exercise tolerance in bike track racing based on analysis of heart rate variability in athletes of various level of training

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ABSTRACT

Assessment of the tolerance of the training load by cyclists who participate in track races is a significant indicator of the adaptive reactivity of the athletes' bodies. The circulatory system of athletes, during cycling races on the track, is subject to colossal functional loads, both during training work and during competitions. The basis of the training process of female cyclists is adaptation to the effects of physical activity, which has a stimulating effect on the course of adaptive reactions of the organism of female athletes in preparation for the competition. A necessary list of heart rate variability indices has been formed, characterizing the degree of tolerance of the training load by cyclists during preparation for competitions on the track. A procedure has been developed for testing the characteristics of the heart rate variability at rest and during the aftereffect of physical activity on the body of cyclists. The results of the influence of the nervous and hormonal regulation of the heart rate on the fitness state of female cyclists are presented. It has been proven that the main indicator of the fitness level of female cyclists is the synchronization of the influence of the nervous and hormonal components of the regulation of the heart rate. The results obtained allow us to recommend the assessment of the degree of synchronization of the nervous and hormonal components of the regulation of the heart rate as the main indicator of the exercise tolerance of cyclists.

Keywords: Performance analisys of sport, Physical conditioning, Cyclists, Bike races on the track, Indicators of heart rate regulation, Level of fitness, Exercise tolerance.

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INTRODUCTION

The circulatory system of female athletes engaged in track cycling is subject to enormous functional loads, during both training and competition. In this regard, systematic control of training load tolerance in female cyclists is an objective factor in sports training management. The basis of the training process is adaptation to the effects of the optimal amount of physical load, which has a stimulating influence on the course of adaptive reactions in female athletes (Bolotin & Bakayev, 2017a; Cooper, 1989; Bilan et al., 2005; Hopkins et al., 2009; Bakayev, 2015). Adaptive reactivity of female athletes' organism manifests in improvement of trophic, regulatory and transport functions of the circulatory system (Bunevicius et al., 2016; Bolotin & Bakayev, 2017b; Daniel, 2009; Begum, 2016; Barcelos et al., 2015; Bakayev, Bolotin & You; 2018; Flatt & Esco, 2015; Kaikkonen et al., 2012; Manso, 2013; Plews et al., 2012). In assessment of tolerance of the training load for female cyclists, it is advisable to take into account the state of the mechanisms of the nervous and neurohormonal regulation of the circulatory system function (Tiwari et al., 2021; Bunevicius et al., 2016; Reimers et al., 2018; Stanley et al., 2013). The effectiveness of synergy between the nervous and neurohormonal regulation of the circulatory system of female athletes engaged in track cycling can be judged by the results of heart rhythm fractal analysis based on the study of cardiographic signal variability. Studying the interaction between nervous and hormonal regulation of the heart rhythm in female track cycling athletes of different training levels will provide insight into the tolerance of physical loads. The objective of the study was to identify differences in the dynamics of parameter values of sympathetic and parasympathetic heart rhythm regulation in female track cycling athletes of different training levels.

Tasks of the study

1. To compare parameter value dynamics of interaction between fast and slow heart rhythm regulation in female cyclists of different training levels at rest and under the influence of standard training load.
2. To identify differences in the parameter value dynamics of neurohormonal heart rhythm regulation in female cyclists with different training levels under the influence of standard training load.
3. To study the trends in heart rhythm variability in high-skill female track cycling athletes based on the identified differences.

MATERIAL AND METHODS

The study participants were high-skill female athletes A. and B. aged 19, who were trained to participate in the Universiade as members of the Russian national team specializing in track cycling. The study was carried out during the basic mesocycle of the autumn-winter half-cycle after the training done in the orientation mesocycle. The scope of training performed on the track as of the beginning of the mesocycle was 3,800 km for female athlete A. and 3,650 km for female athlete B. During the basic mesocycle, both female athletes performed the same work on the track in terms of volume and intensity of the training load. Cardiogram parameters were recorded three times a day: twice at rest and once immediately after exposure to the training load. The obtained data was analysed using the mathematical statistics methods.

In order to determine the fractal components function effectiveness in the circulatory system, we performed a comparison between the dynamic series of heart intervals in female cyclists by quantitative and qualitative parameters.

The study examined the following characteristics

- Parameters characterizing the actual cardiac function (A1 – total regulation effect; A2 – a parameter of the heart self-regulation);

- Parameters characterizing the nervous and vegetative component (B1 – vegetative homeostasis index of the heart rhythm; B2 – index of cardiac rhythm regulation stability);
- Parameters characterizing the state of the hypothalamic-pituitary system (C1 – hypothalamic-pituitary system regulation level index (nervous component of regulation); C2 – hypothalamic-pituitary system regulation level index (endocrine component of regulation));
- Parameters characterizing the state of the central nervous system (D1 – index of “*fast*” adaptation to load; D2 – index of “*slow*” adaptation to load).

The obtained data served as the basis for fractal analysis of the cardiac rhythm in female cyclists, resulting in an energy profile constructed in the form of a content table. The left part of the table reflected assimilation parameters, whereas the right part contained dissimilation parameters. The correlation between parameters in the left and right parts of the table reflected the dynamics of assimilation and dissimilation processes in the organism of female athletes under the influence of training loads. The assimilation parameters characterized the time of energy resources accumulation, whereas dissimilation parameters described the time of energy resources consumption. It was assumed that larger volumes of energy profiles corresponded to more economical energy expenditures of female athletes in performing the same exercise. This ensured minimum energy metabolism in heart rhythm regulation.

Varicard hardware & software system was used to obtain heart rhythm parameters. It helped evaluate the parameters of time and frequency sequence of heart interbit intervals through heart rhythm variability examination methods. The results of the study were provided in form of a detailed report of the following:

- Statistical characteristics of the dynamic series of heart intervals (pulse rate (heart rate-HR), mean square deviation (standard deviation-SD), coefficient of variation (CV));
- Distribution of heart intervals as random variables (variation pulsogram, MO (mode), AM (amplitude of mode), DMM (range – difference between maximal and minimal value);
- Activity degree of the sympathetic division of the autonomic nervous system (rhythmogram of R-R intervals);
- The influence degree of the central control over the autonomic level (autocorrelation function);
- Activity of individual heart rhythm control levels (heart rhythm spectrum).

The statistical characteristic of the dynamic series of heart intervals was estimated by the incremental mean square deviation of the duration of the dynamic series of incremental values of heart intervals (SDSD). SDSD value reflected the total effect of load on the parasympathetic division of the autonomic nervous system in female athletes. SDSD increase indicated the intensified autonomous regulation, whereas its decrease reflected the intensified heart rhythm sympathetic regulation.

Numerical characteristics of the degree of activity of the sympathetic division of the autonomic nervous system were mode (MO), variation span (DMM) and mode amplitude (AM).

AM parameter reflected an increase in centralization of heart rhythm control.

Derivative parameters of variation pulsometry were calculated: regulatory systems’ stress index (SI) and vegetative ratio index (VRI).

The stress index characterized the activity of sympathetic heart rhythm regulation mechanisms and was calculated by the formula: $SI = AM / (2 + \Delta X + MO)$.

The vegetative ratio index (VRI) determined the ratio of sympathetic and parasympathetic heart rhythm regulation and was calculated by the formula: VRI = AM / ΔX.

Correlation rhythmography method was used to evaluate the influence degree of central (sympathetic) mechanisms on the process of the heart self-regulation.

Rhythmogram steepness (IK) (the value of the autocorrelation function at the first shift) was studied. Notably, high correlation between central and autonomous regulation mechanisms corresponded to steepness (IK) increase.

Spectrum analysis of heart rhythm variability was performed to assess load tolerance. Use of spectrum analysis enabled to quantify the activity of individual levels of heart rhythm control. Notably, high-frequency components (HF) characterize parasympathetic activity, low-frequency components (LF) – the activity of the sympathetic division of the autonomic nervous system, while very low-frequency components (VLF) describe dissimilation processes.

Statistical data processing included calculating the arithmetic mean (x); standard square deviation (G); standard error of mean (m); difference significance according to Student's t-test (P).

RESULTS AND DISCUSSION

Dynamics of parameters describing fast and slow heart rhythm regulation at rest and immediately after the training in female athlete A. is shown in Table 1.

The study determined that during the training process, female athlete A. experienced a decrease in sympathetic and an increase in parasympathetic regulation. This indicates neurohormonal regulation component synchronization in the 1st and 2nd microcycles. During intense training, due to the excess load on the organism 's adaptational resources in the 3rd training microcycle, the balance between nervous and hormonal regulation is disturbed. So, in the 3rd microcycle, nerve regulation parameter values (A1, B1, B2) increased and hormonal regulation parameter values (C2, D2) considerably decreased, which indicates a predominance of the central circuit of neurohormonal regulation.

Table 1. Dynamics of fast (FHR) and slow (SHR) heart rhythm regulation in female athlete A. during training.

Parameter	FHR (%)					FHR	SHR (%)			SHR
	A1	B1	B2	C1	D1	mean (%)	A2	C2	D2	mean (%)
1st microcycle										
At rest										
x ± m	86.8 6.8	56.3 5.3	62.4 6.7	61.9 4.8	59.7 5.8	69.1 5.8	42.7 3.3	5.8 2.8	12.7 4.3	9.5 3.7
After training										
x ± m	85.7 2.8	52.5 4.3	63.9 4.7	67.7 5.7	62.8 7.4	70.1 4.3	46.7 4.3	7.7 3.8	17.3 4.7	14.7 4.1
2nd microcycle										
At rest										
x ± m	90.7 5.1	62.4 4.8	59.2* 4.1	62.8 3.8	54.2 8.5	66.7 3.3	46.7 2.7	3.9* 1.3	15.7 1.7	8.9 2.1
After training										

x ± m	93.7 4.8	40.1 4.3	48.7 3.7	50.7* 3.8	33.9 6.7	51.8 4.8	73.7* 2.3	2.7 0.1	17.7 2.4	10.3 1.5
3rd microcycle										
At rest										
x ± m	97.8 0.6	77.9 3.1	66.4 2.3	64.8* 3.1	58.3 3.7	72.7 1.1	67.7 0.7	4.5* 3.7	13.3 1.3	8.7 2.4
After training										
x ± m	99.8 1.9	69.7 5.7	68.2 4.4	56.9* 3.3	62.8* 8.3	69.3 4.3	65.9 6.8	0.7 2.1	7.5 2.2	7.8 1.2

*Note: * p < .05.*

Dynamics of parameters describing fast and slow heart rhythm regulation at rest and immediately after the training in female athlete B. is shown in Table 2.

Table 2. Dynamics of fast (FHR) and slow (SHR) heart rhythm regulation in female athlete B. during training.

Parameter	FHR (%)					FHR	SHR (%)			SHR
	A1	B1	B2	C1	D1	mean (%)	A2	C2	D2	mean (%)
1st microcycle										
At rest										
x ± m	87.4 7.3	58.3 5.7	62.3 6.5	59.7 3.4	61.9 5.9	65.7 4.2	45.9 5.2	5.5 4.9	11.4 3.8	8.3 2.7
After training										
x ± m	86.5 2.3	51.8 4.3	66.7 4.0	60.9 5.3	60.2 4.1	67.3 2.8	40.5 3.4	12.4 6.7	13.5 4.1	15.9 4.8
2nd microcycle										
At rest										
x ± m	94.3* 0.7	64.8* 6.5	53.8 4.1	60.7* 3.8	47.6 8.7	67.1* 4.4	75.8 1.2	0.8 0.3	13.7 0.8	7.8 0.3
After training										
x ± m	85.7 4.1	38.7 3.5	49.7 3.8	51.4 4.7	33.9 6.3	51.3 4.1	70.3 2.3	52.3 3.7	14.8 2.4	10.3 1.1
3rd microcycle										
At rest										
x ± m	98.5* 1.6	75.6 3.7	62.9 2.2	64.8 3.9	59.7 3.6	72.3 1.2	67.3 0.8	0 0	10.8 1.2	8.7 2.4
After training										
x ± m	92.7 2.3	65.9 4.3	67.8 4.4	56.6 2.7	62.3 8.4	69.1 4.3	65.5 1.9	0 0	6.5 2.1	7.9 1.3

*Note: * p < .05.*

The results of comparative analysis show that parameter values of slow heart rhythm regulation in female athlete A. significantly exceed those of female athlete B. Therefore, we may conclude that excessive training work performed by female athlete B. in the process of orientation and medium-load mesocycles negatively affected her functional state. This is confirmed by changes in the ECG in the 2nd standard lead (emergence of a negative T wave, increased QRS complex and a decrease in the S-T segment), indicating the development of myocardial repolarization disturbance due to the excessive physical exertion in female athlete B.

Use of variation pulsometry method enabled to perform comparative analysis by some parameters.

The dynamics of amplitude of mode (AM) is shown in Figure 1.

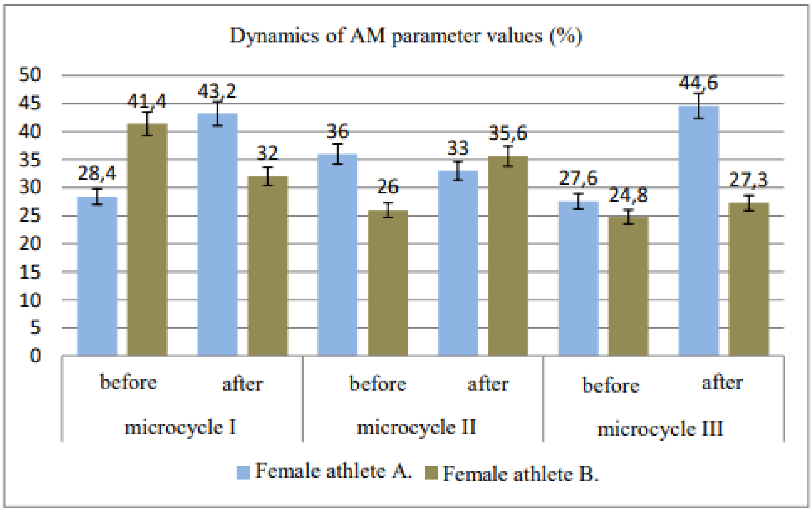

Figure 1. Dynamics of AM (amplitude of mode) of heart interval distribution in female athletes.

The AM parameter characterized the centralization degree of heart rhythm control in female athletes after performing the same amount of exercise on the track. High AM value illustrates the predominance of sympathetic heart rhythm regulation in female athlete B.

The effect of load on the functions of the sympathetic and parasympathetic divisions of the autonomic nervous system in female athletes was examined by the value the mean square deviation of the duration of heart intervals (SDSD). Dynamics of heart interval series in female athletes is shown in Figure 2.

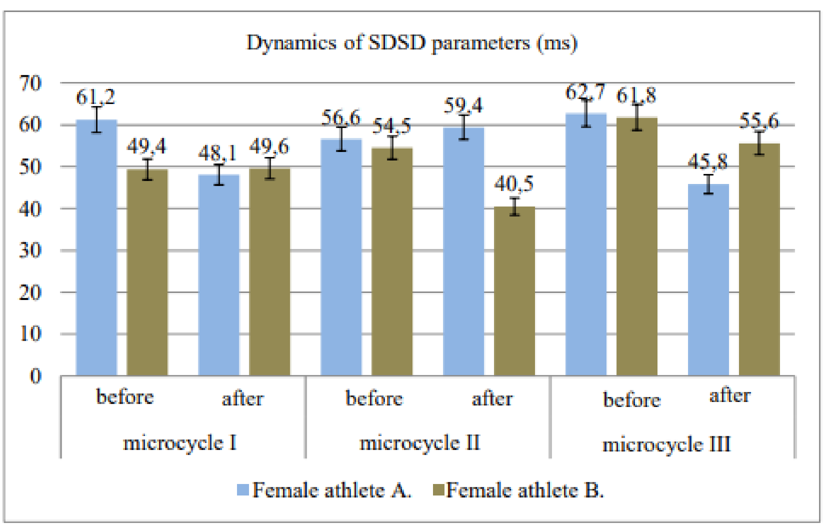

Figure 2. Dynamics of SDNN (square deviation of the duration of heart intervals) parameters in female athletes.

The decrease in SDSD parameter value in female athlete B. illustrates that parasympathetic activity also decreased. This indicates a drop in the training level of the female athlete.

An increase in SDSD value indicated an intensification in autonomous heart rhythm regulation in female athlete A.

The study of stress index of regulatory systems (SI) shows sufficient activity of heart rhythm regulation in both cyclists (Figure 3).

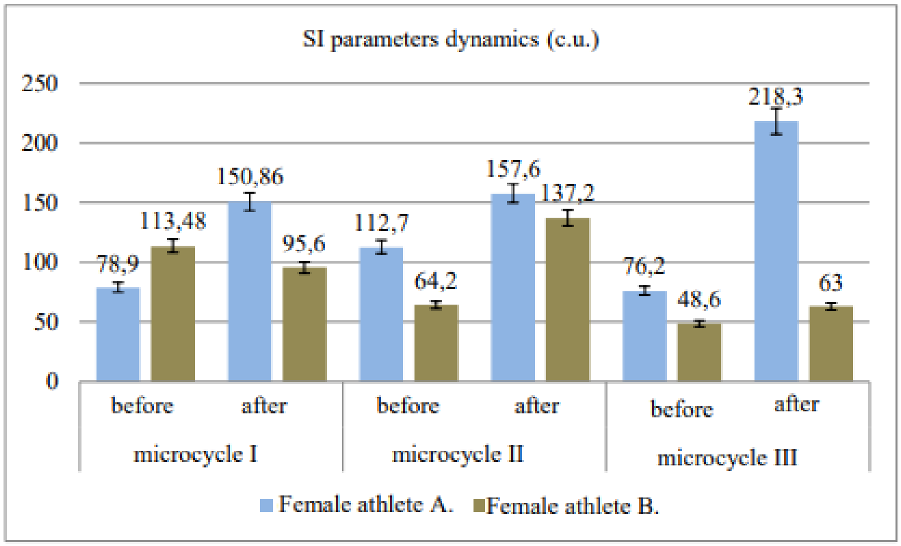

Figure 3. Dynamics of SI (stress index) parameters in female cyclists.

However, the range of changes in SI parameter values in female athlete B. was considerably denser, indicating low adaptation to physical load.

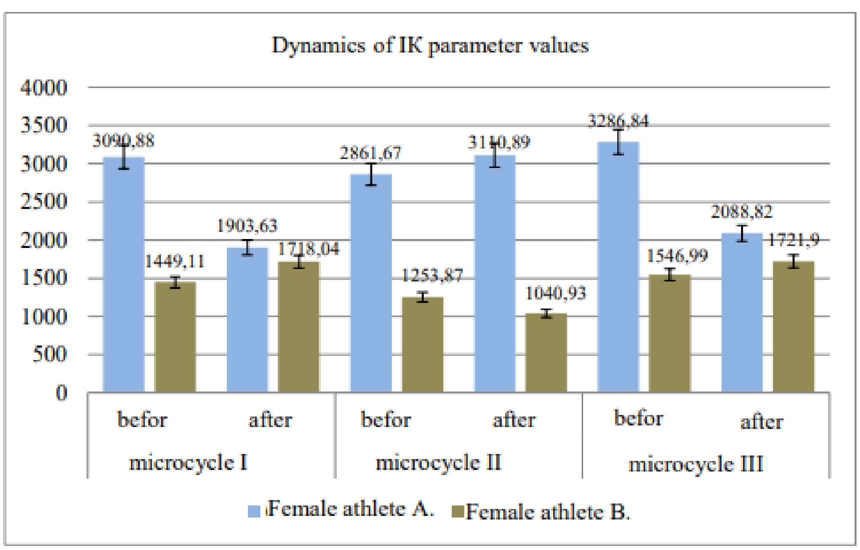

Figure 4. Dynamics of IK (rhythmogram steepness) parameter values in female athletes.

The stress state of the central circuit in female athletes was evaluated by IK parameter (Figure 4).

It was found that in female athlete A., IK parameter value decreased by almost 40% after the training. This suggests activation of the central circuit in cardiac activity regulation.

In female athlete B., IK decreased by 15% only after the training load. This indicates a considerable stress on heart rhythm sympathetic regulation, as well as excessive physical load for this female athlete.

The ratio of central to autonomic heart rhythm regulation was studied on the basis of vegetative balance index (VBI) (Figure 5).

In female athlete A., VBI increased after training. This suggests synchronization of sympathetic and parasympathetic heart rhythm regulation in female athlete A.

In female athlete B., VBI tended to be stable or slightly reduced, indicating an inconsistency in heart rhythm regulation.

Based on the study, female athlete A. showed higher parameter values of fast and slow heart rhythm regulation throughout the basic mesocycle, both before the physical load and after training.

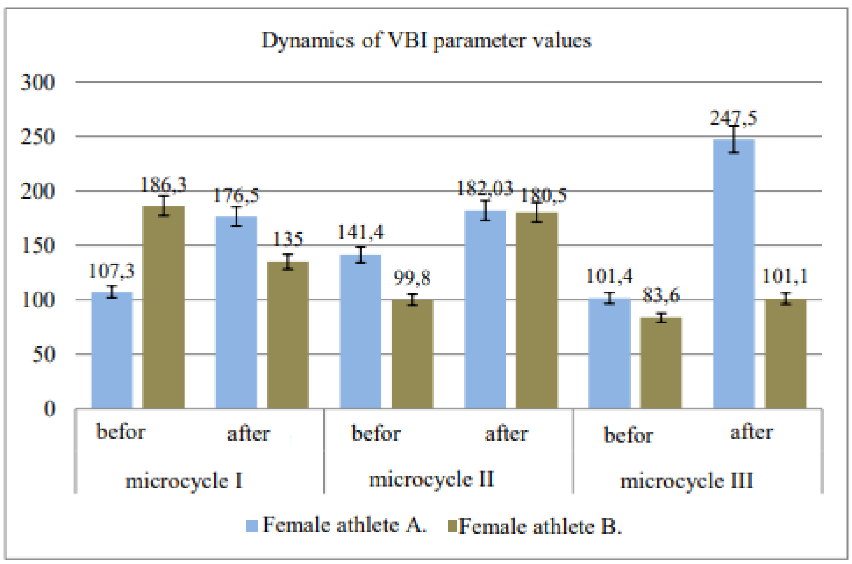

Figure 5. Dynamics of VBI (vegetative balance index) parameter values in female cyclists.

The synchronization of both regulation components in female athlete A. and the mismatch between them in female athlete B. indicate different adaptive reactions of the female athletes' organism to the load. The first one has a higher adaptability, whereas the second one has a considerably lower adaptability. The observed mismatch in the levels of neurohormonal regulation in female athlete B. is the result of chronic fatigue caused by prolonged exposure to excessive physical load that does not correspond to her training level.

CONCLUSION

Apparently, the main criterion for the training level of female cyclists is stable balance between the nervous and hormonal components of heart rhythm regulation. Comparative fractal analysis of heart rhythm variability in high-skill female track cycling athletes allowed to find the following trends in heart rhythm regulation:

- Heart rhythm variability of female athletes depends on coordinated function of nervous and hormonal regulatory systems;
- Decrease in the parameter values of hormonal heart rhythm regulation indicates decreased organism adaptational capabilities;
- Activation of central cardiac regulation under load stress indicates an imbalance between energy assimilation and dissimilation processes;
- Imbalance between nervous and hormonal heart rhythm regulation contributes to the reduction of adaptation resources of the female athletes' organism.

AUTHOR CONTRIBUTIONS

Conceptualization, A.B. and V.B.; methodology, V.B.; software, V.B; data analysis, A.B., V.B.; investigation, V.B. and A.B.; data curation, A.B; writing-original draft preparation, V.B.; writing-review and editing, V.B. All authors have read and agreed to the published version of the manuscript.

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No potential conflict of interest was reported by the authors.

REFERENCES

Bakayev, V., Bolotin, A., & You, C. (2018). Reaction of vegetative nervous system to loads in female long-distance runners with different fitness level. Journal of Human Sport and Exercise, 13(2proc), S245-S252. https://doi.org/10.14198/jhse.2018.13.proc2.09

Bakayev, V. (2015). Determining the significance of practical military skills applied by the special purpose regiments of the Internal Troops of the Russian Ministry of Internal Affairs to deliver combat objectives. Journal of Physical Education and Sport, 15(4), pp. 615-618.

Barcelos LC, Nunes PR, de Souza LR, de Oliveira AA, Furlanetto R, Marocolo M, Orsatti FL (2015). Low-load resistance training promotes muscular adaptation regardless of vascular occlusion, load, or volume. Eur J Appl Physiol., 115(7):1559–1568. https://doi.org/10.1007/s00421-015-3141-9

Begum, N. (2016). Analysis of heart rate variability. Bangabandhu Sheikh Mujib Medical University Journal, 6(2), 84. https://doi.org/10.3329/bsmmuj.v6i2.29120

Bolotin A, Bakayev V. (2017a). Peripheral circulation indicators in veteran trail runners. Journal of Physical Therapy Science, 29: 1092–1094. https://doi.org/10.1589/jpts.29.1092

Bolotin A., Bakayev V. (2017b). The differences in response of the respiratory system of long and middle-distance runners and their influence on recovery rate. Journal of Physical Education and Sport, 17(4), pp.2443-2446. https://doi.org/10.7752/jpes.2017.04272

Bunevicius, K, Sujeta A, Poderiene K, et al. (2016). Cardiovascular response to bouts of exercise with blood flow restriction. Journal of Physical Therapy Science, 29(12), 3288-3292. https://doi.org/10.1589/jpts.28.3288

Bilan, A.; Witczak, A.; Palusinski, R.; Myslinski, W.; Hanzlik, J. (2005). Circadian rhythm of spectral indices of heart rate variability in healthy subjects. J. Electrocardiol., 38, 239–243. https://doi.org/10.1016/j.jelectrocard.2005.01.012

Cooper, K (1989). The aerobics program for total well-being. Physical Education and Sport, Moscow, 224 p.

Daniel, S. (2009). Abnormal blood flow in the sublingual microcirculation at high altitude. Eur. J. Appl. Physiol., (106), 473-478. https://doi.org/10.1007/s00421-009-1023-8

Flatt, A.A.; Esco, M.R. (2015). Smartphone-Derived Heart-Rate Variability and Training Load in a Women's Soccer Team. Int. J. Sports Physiol. Perform., 10, 994–1000. https://doi.org/10.1123/ijspp.2014-0556

Hopkins, W.G.; Marshall, S.W.; Batterham, A.M.; Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. Med. Sci. Sports Exerc., 41, 3–13. https://doi.org/10.1249/mss.0b013e31818cb278

Kaikkonen, P.; Hynynen, E.; Mann, T.; Rusko, H.; Nummela, A. (2012). Heart rate variability is related to training load variables in interval running exercises. Eur. J. Appl. Physiol., 112, 829–838. https://doi.org/10.1007/s00421-011-2031-z

Manso, J.M. (2013). Application of Heart Rate Variability in sports training control: Frequency mode analysis. Archivos de Medicina del Deporte. 30. 43-51.

Plews, D.J.; Laursen, P.B.; Kilding, A.E.; Buchheit, M. (2012). Heart rate variability in elite triathletes, is variation in variability the key to effective training? A case comparison. Eur. J. Appl. Physiol., 112, 3729–3741. https://doi.org/10.1007/s00421-012-2354-4

Reena Tiwari, Ravindra Kumar, Sujata Malik, Tilak Raj and Punit Kumar (2021). Analysis of Heart Rate Variability and Implication of Different Factors on Heart Rate Variability. Current Cardiology Reviews, 17(5). https://doi.org/10.2174/1573403x16999201231203854

Reimers, A.K.; Knapp, G.; Reimers, C.-D. (2018). Effects of Exercise on the Resting Heart Rate: A Systematic Review and Meta-Analysis of Interventional Studies. J. Clin. Med., 7, 503. https://doi.org/10.3390/jcm7120503

Stanley, J.; Peake, J.M.; Buchheit, M. (2013). Cardiac parasympathetic reactivation following exercise: Implications for training prescription. Sports Med., 43, 1259–1277. https://doi.org/10.1007/s40279-013-0083-4