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Formation and Regression of Sports Vagotonia (Based on Heart Rate Variability Data Under Clinostasis Conditions)

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Abstract

Analysis of the values of 15 heart rate variability (HRV) indices recorded under clinostasis conditions showed that elite skiers of the Republic of Tatarstan (ESRT) in the preparatory period had higher activity of the parasympathetic division (PD) of the autonomic nervous system (ANS), and lower activity of the sympathetic division (SD) of the ANS than skiers of the 1st and 2nd adult categories (YSRT). It was shown that over the course of 6 months of this period, the medians of HF% and RRNN increased in ESRT, while the medians of APHF, HF%, APVLF, VLF%, APLF, APLF/APHF, RRNN, HR and RMSSD decreased, while they did not change in TP, LF%, pNN50%, SDNN, MxDMn and SI. In YSRT, the medians of 3 indicators changed during the preparatory period - in HF% it decreased, and in LF% and APLF/APHF it increased. It was shown that during the 6 months of this period, in ESRT the medians HF% and RRNN increased, the medians APHF, APVLF, VLF%, APLF, APVLF/APHF, HR and RMSSD decreased, and the medians of the remaining 6 indicators (TP, LF%, pNN50%, SDNN, MxDMn, SI) did not they change. During the preparatory period In YSRT the medians of 3 indicators changed it decreased in HF%, and in LF% and APLF/APHF - increased. This means that the activity of PD ANS and, probably, the level of synthesis of neuronal acetylcholine (NN-ACh) remains stable during the preparatory period in ESRT and YSRT, but they are lower in YSRT than in ESRT. Consequently, long-term (13-20 years) continuous high-volume training is required for the formation of sports vagotonia, which, in addition to increasing ANS activity, is probably based on the production of HH-ACh by cardiomyocytes. It was shown that a 7-month (from April 2024 to October 2024) forced (due to damage to the tendons of the adductor muscles of the left thigh) cessation of training by an elite skier K.D. was accompanied by a gradual decrease (to the level typical for non-athletes) of medians TP, APHF, HF%, APVLF, APLF, RRNN, pNN50%, RMSSD, SDNN, MxDMn, with an increase in the medians of VLF%, HR and SI, while the medians LF% and APLF/APHF remained unchanged. Consequently, in conditions of complete lack of training, there is a rapid decrease in the activity of SD of ANS, and probably (NN-ACh) i.e., an almost complete regression of sports vagotonia.

Keywords: Heart Rate Variability, Clinostasis, Cross-Country Skiers; Adaptation to Physical Activity, Autonomic Nervous System, Sports Vagotonia and Its Formation and Regression; Non-Neuronal Acetylcholine

Abbreviations: HRV: Heart Rate Variability; ESRT: Elite Skiers of the Republic of Tatarstan; PD: Parasympathetic Division; ANS: Autonomic Nervous System; SD: Sympathetic Division; ROS: Reactive Oxygen Species; TC: Training Camps; ARS: Adduktor-Rectus-Symphysis; CIG: Cardio Interval Gram; RT: Republic of Tatarstan

Introduction

It is known that the formation of a high level of endurance requires long-term continuous training loads of long duration at a relatively high intensity, i.e., of an aerobic nature [1,2]. One of the proofs of this position is the fact that the winners of the World Championships and the Winter Olympic Games in cross-country skiing, namely in the 50 km ski marathon, are athletes whose average age is 26-29 years and who have a long experience in this sport [1]. It is shown that only 0.83% of cross-country skiers aged 15-16 who became winners and prize-winners of All-Russian competitions among average boys aged 15-16 fall into the list of the top 40 male skiers in Russia, and only 0.56% of them compete at the World Cup [2]. Earlier, based on the analysis of literature data [3-5] on the ability of the human and animal hearts to synthesize non-neuronal acetylcholine (NN-ACh), as well as on the basis of an analysis of the values of heart rate variability (HRV) indicators of representatives of different sports, it was suggested that sports vagotonia, characteristic of endurance athletes, including for ski racers, it is caused not only by increased activity of the parasympathetic division of the autonomic nervous system (PD of ANS), but also the ability of cardiomyocytes of the heart ventricles to synthesize non-neuronal acetylcholine (NH-ACh) [6]. At the same time, NN-ACh, along with PD of ANS, is considered as a component of the anti-apoptotic system, due to which the heart, performing a great job as a pump under the influence of catecholamines, remains viable, despite the presence of high levels of reactive oxygen species (ROS) and the damaging effects of catecholamines activating beta1-AR of the myocardium [6,7].

The purpose of this article is to further confirm this hypothesis based on an analysis of the dynamics of the medians of 15 HRV indicators recorded in clinostasis conditions among elite ski racers and less qualified ski racers in the older age group of 17-18 years during the preparatory period, as well as an analysis of the dynamics of 15 indicators of clino- HRV of an elite ski racer. K., D. (master of sports) for 7 months after the forced cessation of training loads. The working hypothesis of the article. In the process of endurance training, the synthesis of HH-ACh increases. The intensity of HH-ACh synthesis reaches its maximum among elite skiers, while its level is not high enough for less qualified skiers with the 1-st or 2-nd adult category. Therefore, the process of adapting to training loads in the preparatory period proceeds differently for elite skiers and less qualified skiers. In particular, in both cases, the activity of the SD of ANS increases, but it is countered by the activity of PD of ANS, which is realized due to vagal ACh and NN-ACh. The higher the level of NN-ACh, the higher the ability of PD ANS to suppress excessive activity of SD of ANS especially in conditions of clinostasis. When an elite skier is forced to stop training, there is a gradual decrease in activity of PD ANS, which is due, among other things, to a decrease in the synthesis of NN-ACh.

Research Methods

From June to November 2019, i.e., during the preparatory period, heart rate variability (HRV) was studied almost daily (in clinostasis) There are 8 elite ski racers, members of the men's national team of the Republic of Tatarstan (further - ESRT), including 6 master of sports, and 2 masters of sports of international class. Their ages ranged from 23 to 31 years old, and their work experience ranged from 13 to 20 years. Among them was Skier K.D. (MS, the first author of the article). Training camps (TC) and competitions for elite skiers were held in different regions of Russia and beyond, including in lowland and mountainous climatic conditions, as previously reported in detail [7]. The second group of the study consisted of 11 ski racers of the 1st and 2nd adult categories - members of the youth national team of the Republic of Tatarstan (further YSRT), who represented the age group "senior boys 17-18 years old." Their skiing experience was 5-7 years, i.e., much less than that of the ESRT. Their registration of HRV under the conditions of clinostasis was also carried out during the preparatory period (from June to November 2023).The training camps of this group took place in June at the Yalchik recreation center (Republic of Mari El); in July - in Mirny (Republic of Tatarstan); in August - in Dombay (Republic of Karachay-Cherkessia) at an altitude of 1600 m; in September and October - in Mirny (Republic of Tatarstan), in the first half of November - at the Pearl of Siberia Winter Sports Center (Tyumen Region), and in the second half of November - at the R. Smetanina Ski Complex (Komi Republic).

The preparatory period for ESRT and YSRT was carried out for 6 months. Each month included 2-3 microcycles, i.e., 2-3 weeks, and a week of rest at home. Each microcycle consisted of 5 training days (2 workouts + morning exercises), one unloading day (1 workout per day) and a day off (without training). During the week-long rest period between the next training camp, the skiers conducted 1 training session per day at home. In both groups, track and field and cross-country running, roller skiing, and cross-country skiing formed the basis of training in the preparatory period. According to the data recorded by the skier K.D. in 2019, during the preparatory period, the total load of the ESRT was 5,278 km or 375.5 hours, in particular, in June - 989 km (66.5 h), in July - 1180 km (70 h), in August - 857 km (72 h), in September - 876 km (57.5 h), in October. - 578 km (50 h), in November - 597 km (55 h). According to the data recorded by the leader of the YSRT, the total training load for the entire preparatory period was 3,495 km or 371 hours, in particular, in June - 771 km (82 h), in July - 672 km (62 h), in August - 450 km (55 h), in September - 636 km (61 h), in October - 369 km (56 h), in November - 597 km (55 h). Thus, although the total duration of training for the YSRT was the same as for the ESRT, the mileage was lower, and therefore the average speed of movement was lower (9.4 km/h versus 13.1 km/h), since their physical fitness did not allow them to develop the same performance as the ESRT.

The third section of our work concerned the study of regression of sports vagotonia. The implementation of this section occurred accidentally due to the fact that in March 2024, an elite skier, K.D., suffered damage to the tendons of the adductor muscles of the left thigh during the training process, which, as is known [8], is characteristic of Adduktor-Rectus-Symphysis syndrome (ARS). For this reason, K.D. was forced to stop the training process, while maintaining everyday (household) physical activity. The presence of an interval cardiographer and research experience as a former graduate student of Vyatka State University (specializing in physiology) provided a unique opportunity to analyze the nature of changes in HRV indicators in April, June, August and October 2024, i.e., for 7 months under conditions of complete cessation of training loads, which he had until March 2024. Since the beginning of this "training-free" period coincided with the transition period

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of the annual cycle of ski racers, the HRV indicators registered with K.D. in April-October 2024 were compared with the data obtained during the study of K.D. (as a member of the ESRT) during the transition period, i.e., in June 2019 and in June 2020 (respectively, the first and second points of comparison).

All the subjects, including ESRT and YSRT, had their cardiointervalogram (CIG) recorded personally by K.D., who is the first author of the article. HRV was recorded for 5 minutes with the subject in the "supine" position (clinostasis) after a night's sleep, before breakfast, and in comfortable conditions. The VNS-Micro system (Neurosoft, Russia) was used, and the Polyspectrum program (Neurosoft, Russia) was used for CIG analysis. The generally accepted 8 spectral and 7 temporal parameters of HRV were analyzed. Among the spectral indicators of HRV are the total power of the spectrum (TP, mc2), or total power; the absolute power (mc2) of fast (HF-) waves, slow (LF-) waves and very slow (VLF-) waves (further, respectively, APHF, APLF and APVLF); the ratio APLF/APHF; the relative power of HF-, LF-, and VLF- waves, i.e., the wave power expressed as a percentage of TP (further - HF%, LF%, and VLF%, respectively). Among the time indicators, the duration of normal R-R intervals (RRNN, ms) was analyzed, which is analogous to heart rate (HR, beats/min); the ratio of consecutive NN-intervals, the difference between which exceeds 50 ms, as a percentage of the total number of normal (NN) R-R intervals (pNN50%); the square root of the average the square of the differences in the values of consecutive pairs of NN intervals (RMSSD, ms); the standard deviation of all NN intervals (SDNN, ms); the variation range (MxDMn, ms), i.e., the difference between the maximum and minimum R-R intervals; as well as the stress index (SI, conventional units), which was calculated using the formula: SI = AMo / Mo × 2MxDMn, where AMo is the amplitude of the mode, i.e., the most common value of the R-R-intervals of ECG , expressed as % of all R-R intervals; Mo -is the absolute value of the mode (s), and MxDMn is the variation range, i.e., the difference between the maximum and minimum values of the R-R intervals (s).

The assessment of these indicators was formed by summing up the results of individual studies in each month of the preparatory period (ESRT, YSRT) or the studied month of the "non-loading" period at K,D. In general, the ESRT had 146 HRV-registrations, the YSRT had 141 registrations, and at K,D. had 85 registrations, including in April, June, August and October, respectively, there were 19, 22, 29, and 15 registrations. All results were expressed as medians, 25 and 75 centiles [9]. The Mann-Whitney criterion was used to evaluate the differences, considering them statistically significant at $p < 0.05$ [9]. For calculations, including the Spearman correlation coefficient, we used the BioStat 2009 Professional, 5.9.8 program (Analyst Soft company). All studies were approved by the local Bioethical Committee of Vyatka State University (Protocol No. 1 dated 17.01.2020).

The Results of the Study and their Discussion

Comparison of the Medians Of 15 Clino- Indicators of HRV ET ESRT and YSRT for the Entire Preparatory Period (June-November) and for Monthly

In general, a comparison of the medians of clinio- HRV indicators in ESRT and in YSRT for the entire period (Table 1, Figure 1) shows that the medians of the 14 indicators differed, at the same time, in 9 of them, reflecting mainly PD of ANS activity, they were higher in ESRT than in YSRT - these are TP, APHF, APVLF, HF%, RRNN, pNN50%, RMSSD, SDNN and MxDMn, and 5 indicators reflecting the activity of the SD of ANS were lower (APLF, LF%, APLF/APHF, HR, SI) than those of the YSRT, and only the median of one indicator did not differ (VLF%). This suggests that in ESRT has a higher effect on PD of ANS, including probably a higher level of NN-ACh, but below effect of SD of ANS (in conditions of clinostasis). Analysis of the TP components shows that HF- waves occupy the first place in ESRT, VLF- waves occupy the second place, and LF-waves occupy the third place (APHF>APVLF>APLF), while YSRT has VLF- waves in the first place, LF- waves in the second place, and HF-waves in the third place (APVLF>APLF>APHF).

This indicates that in the conditions of clinostasis, in ESRT is dominated by the effect of PD of ANS on heart activity, and to a lesser extent by SD of ANS, and in YSRT the effect of SD of ANS on the heart is higher than the effect of PD of ANS. In each of the six months of the preparatory period (Table 1, Figure 1) the medians of the 4 clino-HRV indices (HF%, RRNN, pNN50%, RMSSD) in ESRT were higher than in YSRT, and the median HR was lower the medians of the remaining 9 indicators of clino-HRV in ESRT and in YSRT did not differ in any of the months, although there were differences in general over the entire period. In particular, the medians of such indicators as TP, APVLF, SDNN, MxDMn differed statistically significantly only in June and July, which was not observed in the remaining four months of the preparatory period. There were no differences for the median APHF in June and October, for the median LF% in August, and for the median APLF/APHF - in June and August, for the median SI - in October. For median differences of APLF were not observed in all 6 months, but were present for the entire period as a whole. At the same time, the median of VLF% for both ESRT and YSRTS was the same in each month and for the entire period as a whole.

So, these results confirm the literature data [6,7,10-14] that ESRT, in comparison with YSRT in clinostasis conditions, has higher the median indicators reflecting the activity of PD of ANS and lower the median of indicators, which reflecting the activity of SD of ANS. This is consistent with the assumption that as the experience of skiing increases and, consequently, as athletic skill increases, the influence of PD of ANS on the activity of the heart increases and at the same time an anti-apoptotic system is formed

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in it, the component of which is NN-ACh. It is obvious that PD of ANS together with NN-ACh reduces the manifestation of the activity of SD of ANS in conditions of clinostasis (additional evidence of this assumption is given below), although it is precisely due to the high activity of SD of ANS that it is possible to achieve high athletic results in cross-country skiing.

Monthly Dynamics of Median Clino-HRV Indicators During the Preparatory Period in ESRT and YSRT Groups

During the preparatory period, which takes six months in a row, the dynamics of the medians of 10 indicators (out of 15) for ESRT and for YSRT were different (Table 1, Figure 1) and at the same time, in each of the groups (ESRT, YSRT), it depended on the amount of training load, which changed in each microcycle, as noted in the section "Research methods". Thus, in ESRT, the medians of 6 indicators (TP, LF%, pNN50%, SDNN, MxDMn, and SI) remained stable throughout the 6 months of the preparatory period, and the medians of 9 indicators changed during the preparatory period, including the medians of APHF, APVLF, VLF%, APLF, APVLF/APHF, HR and RMSSD, and the medians of HF% and RRNN increased. In particular (tab. 1), the median of APHF decrease by 5142 to 3264 mc2, it is on 35%, in september; median of APVLF decreased by 3726 to 1711 mc2. (it is on 35% in October); median of VLF% decreased by 35.6% to 25.0% (october); median of APLF decreased by 2300 ms2 to 1316 ms2 (it is on 43%, october); median of APLF/APHF decreased by 0.48 s.u. up to 0.34 s.u. (it is on 0.1 s.u., october); median of HR decreased by 43.2 b/min to 39.8 b/min (it is on 8%, november) and the median of RMSSD decreased by 129 ms to 100 ms (it is on 22%, september).

The median of HF% increased from 45% to 56.5% in october, and the median RRNN increased from 1388 ms to 1506 ms, i.e., on 8.5%, in november. Note that a decrease in the medians of APHF, RRNN and RMSSD indicates a decrease in the effect of PD of ANS and NN-ACh on the heart, while an increase in the medians of HF% and RRNN and a decrease in the medians of APLF/APHF and HR, on the contrary, indicate an increase in the effect of PD of ANS, while the absence of changes in the medians of TP, pNN50%, SDNN, MxDMn, and SI speaks about maintaining influence PD of ANS on cardiac activity. These data allow us to conclude that during the preparatory period, ESRT retains a high activity of PD of ANS and, probably, a high level of synthesis of NN-ACh. At the same time, in conditions of clinostasis, the high activity of the SD of ANC, which is typical for elite skiers in competitive conditions, does not significantly effect on the clino-HRV indices, which is probably explained by the inhibitory effect of PD of ANC and NN-ACh. The question of the reasons for the decrease of the medians of such indicators as APHF, APVLF and VLF% in the ESRT in the preparatory period remains open. It is possible that this is due to the fact that during training NN-ACh is used as an anti-apoptotic agent and therefore the content of NN-ACh temporarily decreases, which is reflected in a decrease in the medians of these indicators, which, in our opinion [7], most reflect the level of synthesis of NN-Ach.

Unlike ESRT, only three indicators change during the preparatory period for YSRT - LF%, HF% and APLF/APHF. At the same time, the median of HF% decreased from 35.3% to 22.6% (in september); the median of LF% increased from 26.3% to 37.7% in november, and the median of APLF/ APHF increased from 0.76 c. un to 1.30 c. un in november. The remaining 12 indicators of clino-HRV in YSRT did not change throughout the entire preparatory period. This suggests that the activity of PD of ANS and, probably, the level of synthesis of NN-ACh during the preparatory period in YSRT remains stable, but lower than in ESRT, and also suggests that in conditions of clinostasis the ability of PD of ANS and NN-ACh is probably insufficient to inhibit activity of SD of ANS. This is partially indicated by data according to which, during the preparatory period, both in ESRT and in YSRT experienced an increase in the mediansn of APLF, LF% and APLF/APHF, reflecting the activity of SD of ANS, but at the same time, this growth was less pronounced in ESRT than in YSRT. So, in ESRT the median of APLF increased from 2300 ms2 (June) to 2912 ms2 in august; i.e., on 26.7% ($p > 0.05$), and in november it even decreased to 1360 ms2 ($p < 0.05$), and in YSRT it increased from 1740 ms2 (in June) to 3037 ms2 (in November), i.e., on 77.4%.

The median LF% in ESRT increased from 21.0% (June) to 21.8% in November, i.e., on 0.8% ($p > 0.05$), and in YSRT it increased from 26.3% (June) to 37.7% (November), i.e., on 11.4% ($p < 0.05$). Median of APLF/APHF in ESRT increased from 0.48 c.un. to 0.56 c.un. (November), i.e., on 0.08 c.un. ($p < 0.05$), and in YSRT it increased from 0.76 c.un. (June) to 1.30 c.un. (November), i.e., on 0.54 c.un. ($p < 0.05$). We do not exclude that in conditions of clinostasis, the high activity of PD of ANS and the high level of production of NN-ACh, characteristic for ESRT, suppresses the effect of SD of ANS on cardiac activity to a greater extent than in YSRT, in which the intensity of synthesis of NH-AH is probably lower than in ESRT. This conclusion is also confirmed by the fact that, in general, for the entire preparatory period, as noted above, the medians LF%, APLF/APHF, HR, and SI were higher in YSRT than in ESRT. So, the results of our research indicate differences in the dynamics of the median of clino-HRV iundices in ESRT and in YSRT during the 6-month preparatory period. In our opinion, these differences are explained by the different levels of synthesis of NN-ACh, which is most likely higher in ESRT than in YSRT. Therefore, the difference we have identified between ESRT and YSRT can be regarded as another indirect evidence of the presence of NN-ACh synthesis in the heart of a person exercising endurance.

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It is important to emphasize that the medians of the 5 indicators (TP, pNN50%, SDNN, MxDMn, and SI) did not significantly change during the preparatory period for either ESRT or YSRT, although the medians of these indicators for ESRT were statistically significantly higher than for YSRT. So, initially, the median TP for ESRT was 10,862 ms2, and for YSRT it was 7,101 ms2; the median of pNN50% was 70.1% and 48.9%, respectively, the median of SDNN was 112 ms and 85 ms, the median of MxDMn was 584 ms and 492 ms, and the median of SI was 13.1 c. un. and 28.7 c. un. respectively. Obviously, these indicators, unlike APHF, APVLF, VLF% reflect mainly the activity of PD of ANS, and to a lesser extent reflect the level of NN-ACh.

So, during endurance training, the activity of SD of ANS and PD of ANS increases, while the increase in activity of PD of ANS is probably associated with an increase in the production of NN-ACh, which increases its effect on the heart and simultaneously (together N-Ach of vagus) reduces the manifestation of SD of ANS activity in the conditions of clinostasis. However, the production level of NN-Ach in YSR is still not high enough, i.e., it is not able to suppress the activity of the SD of ANS in conditions of clinostasis.

The question of why it was not possible to record an increase in activity of PD of ANS and increase of level synthesis of NN- ACh in YSRT during the preparatory period remains open. Perhaps this growth occurs during the transition period, when the volume of training loads decreases and the stress associated with the expectation of competition decreases, which contributes to the synthesis of NN-ACh.

The Dynamics of the Clino-HRV Indicators of the Elite Skier K.D. for 7 Months from the Moment of the Forced Cessation of Training Loads

The data presented in Table 2 and Figures 2 and 3 show that of the 15 HRV indicators recorded in clinostasis, the medians of 10 indicators are statistically significantly decreasing by October 2024. These are TP (by 62%), APHF (by 71%), HF% (by 10%), APVLF (by 52%),), APLF (by 67%), RRNN (by 18%), pNN50% (by 24.9%), RMSSD (by 51%), SDNN (by 43%) and MxDMn (by 50%). At the same time, the medians of 3 indicators increase, including VLF% (by 5.4%), HR (by 8.8 beats per minute), and SI (by 38 c.un), and only the medians of two indicators do not change, including LF% (21.2-21.1) and APLF/APHF (0.61-0.63). Obviously, the longer the period of cessation of exercise, the more pronounced the decrease in the medians of 10 indicators (TP, APHF, HF%, APVLF, APLF, RRNN, pNN50%, RMSSD, SDNN and MxDMn) and the increase in the medians of 3 indicators (VLF%, HR and SI). All this can be explained by a decrease in PD of ANS activity and, probably, a decrease in the intensity of NN-ACh synthesis in an elite skier. The question of to what level the decline in production of NN-Ach occurs remains open, since our judgment is based only on data on the values of HRV indicators. We believe that even 7 months after the cessation of training, the synthesis of NN-ACh in an elite skier is still preserved, but its level is significantly reduced.

Indeed, in October 2024, the median of 4 indicators (LF%, APLF/APHF, RRNN, HR) in K.D. were between the medians of appropriate indicators in ESRT and YSRT. Thus, the median of LF% for ESRT was 16.3%, for YSRT - 24.4%, and for K. D - 21.1%; the median of APLF/APHF for ESRT was 0.34 c. un., for YSRT - 0.84 c. un. and for K. D - 0.63 c. un; the median of RRNN, for ESRT was 1440 ms, for YSRT - 1038 ms, and , for K. D - 1197 ms (Figure 2); the median heart rate for ESRT was 42.0 beats/min, for YSRT - 51.7 beats/min, and for K. D - 50.1 beats/min. However, the medians of 9 other clino- HRV indicators in K.D. are lower than in ESRT and YSRT. These are:

1) the median of TP for ESRT was 8612 ms2, for YSRT - 7705 ms2, for K.D. - 3682 ms2 (Figure 3);

2) the median of APHF for ESRT was 4102 ms2, for YSRT - 3747 ms2, and for K.D.- 1141 ms2;

3) the median of HF% for EST was 56.5%, for YSRT - 43.6%, and for K.D. - 31.0%;

4) median of APVLF for ESRT was 1711 ms2, for YSRT - 2627 ms2, and for K.D. - 1586 ms2;

5) median of APLF for ESRT was 1316 ms2, for YSRT - 1734 mc2, and for K.D. - 752 mc2;

6) the median of pNN50% for ESRT was 71.4%, for YSRT - 51.7%, and for K.D.- 45.4%;

7) the median of RMSSD for ESRT was 118 ms, for YSRT - 80 ms, and for - 58 ms;

8) the median of SDNN for ESRT was 91 ms, for YSRT - 88 ms, and for K.D.- 58 ms;

9) the median MxDMn for ESRT was 529 ms, for YSRT - 485 ms, and for K.D - 305 ms . And only the median of the stress index (SI) was higher in K. D (49 c.un). than in ESRT (16.1 c.un) and YSRT (26.9 c.un) All this means that the synthesis of NN-ACh in K.D. through the 7-month «workout-free» period has been significantly reduced, but it is probably still happening.

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Table 1: Median, 25, and 75 values of the spectral and temporal parameters of clino-HRV in ESRT and YSRT during each of the 6 months of the preparatory period and for the entire period as a whole.

Clino-HRV Indicators	Months of the Preparatory Period												Entire Prepara-tion	
	June (6)		July (7)		August (8)		Septem (9)_		Octob (10)_		Novemb (11)			
	YSRT	TESRT	YYSRT	ESRT	YSRT	ESRT	YSRT	ESRT	YSRT	ESRT	YSRT	ESRT	YSRT	ESRT

Show. clino-HRV	Months of the Preparatory Period												All preparation period	
	June (6)		July (7)		August (8)		September (9)		October (10)		November (11)			
	YULRT	ELRT	YULRT	ELRT	YULRT	ELRT	YULRT	ELRT	YULRT	ELRT	YULRT	ELRT	YULRT	ELRT
TP, мс^2	7101 5369/13952	10862* 7724/19020	7412 5448/9370	10071* 5862/15784	8520 5561/10521	11201 8143/21088	8339 5208/11614	9420 6545/11993	7705 5846/10695	8612 4736/11822	7574 5118/20160	9913 7188/12358	7762 5267/11514	9923* 6658/14428
Difference	-	-	-	-	-	-	-	-	-	-	-	-	-	-
APHF, мс^2	2060 1473/6856	5142 3343/8243	1847 1323/3650	3990* 2209/7039	2706 1698/4206	4541* 2608/7656	1885 921/3393	3264* 2493/4552	3747 936/5369	4102 2938/5647	1541 1223/4709	3359* 2391/4910	2026 1307/4313	4082* 2576/6336
Difference	-	-	-	-	-	-	-	6	-	-	-	-	-	-
HF, %	35.3 25/61	45.0* 35/52	26.6 20/34	41.4* 32/49	33.9 23/47	44.2* 26/53	22.6 18/31	39.9* 26/46	43.6 19/51	56.5* 45/61	21.2 17/30	44.0* 34/48	28.8 20/39	43.6* 32/52
Difference	-	-	6	-	7	-	6, 8	-	-	7, 8, 9	6, 8	10	-	-
APVLF, мс^2	2083 1134/3229	3726* 2239/4462	1849 1173/3978	2941* 1800/5577	2764 1389/3869	3540 2090/6190	2361 1543/5577	3397 1961/5952	2627 1662/3416	1711 1096/3075	2539 1526/5028	3495 2222/5891	2379 1329/3874	3138* 1818/5611
Difference	-	-	-	-	-	-	-	-	-	6, 7, 8, 9	-	10	-	-
VLF, %	28.7 16/39	35.6 20/39	30.5 22/45	39.1 32/48	31.1 25/42	33.2 26/52	35.5 22/46	36.7 29/55	28.9 15/41	25 15/31	30.5 21/41	34.1 24/42	30.5 21/43	34.1 24/45
Difference	-	-	-	-	-	-	-	-	-	6, 7, 8,9	-	10	-	-
APLF, мс^2	1741 1425/2965	2300 1373/3605	2480 1537/4101	2013 1123/2994	1526 1108/5260	2912 974/4305	2791 1514/4398	1912 1403/2684	1734 1366/3557	1316 895/2755	3037 1611/6225	2101 1298/3220	2159 1402/4480	2057* 1119/3202
Difference	-	-	-	-	-	-	-	-	-	6	8	-	-	-
LF, %	26.3 15/37	21.0* 15/22	35.9 19/47	19.3* 13/24	24.3 17/43	21.1 12/27	34.3 23/50	20.8* 14/24	24.4 20/34	16.3* 12/23	37.7 29/55	21.8* 14/26	30.6 20/48	19.9* 14/25
Difference	-	-	-	-	-	-	-	-	-	-	6, 8	-	-	-
APLF/ APHF, c. un.	0.76 0.23/1.65	0.48 0.32/0.64	1.07 0.78/2.24	0.48* 0.38/0.65	0.59 0.43/1.32	0.51 0.33/0.71	1.28 0.83/2.34	0.55* 0.4/0.75	0.84 0.39/1.66	0.34* 0.22/048	1.3 0.98/2.97	0.56* 0.41/0.65	1.06 0.6/2.2	0.50* 0.3/0.65
Difference	-	-	6	-	7	-	6, 8	-	-	7, 8, 9	6, 8	10	-	-
RRNN, ms	1007 943/1120	1388* 1272/1460	1086 983/1218	1438* 1324/1539	1112 882/1189	1339 * 1236/1466	1036 965/1185	1464* 1293/1521	1038 962/1107	1420* 1282/1484	1049 934/1179	1506* 1398/1540	1042 951/1189	1430* 1291/1515
Difference	-	-	-	-	-	7	-	-	-	-	-	6, 8, 10	-	-
HR, b/min	59.5 53/63	43.2* 41/47	55.3 49/61	41.7* 39/45	54 50/68	44.7* 40/48	57.9 50/62	41.0* 39/46	57.8 54/62	42.2* 40/46	57.2 50/64	39.8* 38/42	57.6 50/63	42.0* 39/46
Difference.	-	-	-	-	-	7	-	-	-	-	-	6, 8, 10	-	-
pNN50, %	48.9 40/61	70.1* 56/79	48 39/53	68.2* 58/74	51.6 40/65	67.8* 47/73	44 26/59	66.3* 60/71	51.7 37/57	71.4* 66/78	44 32/62	68.4* 63/74	48.2 37/61	68.8* 58/75
Difference	-	-	-		-	-	-	-	-	-	-	-	-	-

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RMSSD, ms	79 61/110	129* 108/154	78 64/99	115* 92/156	81 71/110	114* 80/177	70 57/104	100* 90/110	80 65/98	118* 93/125	72 55/136	101* 91/119	78 60/102	110* 92/135
Difference	-	-	-	-	-	-	-	6	-	-	-	-	-	-
SDNN, ms	85 76/112	112* 88/135	87 75/101	104* 81/124	94 74/104	102 91/136	89 74/111	88 82/116	88 78/103	91 74/103	90 71/142	95 82/110	88 74/107	99* 84/123
Difference.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MxDMn, ms	492 396/557	584* 549/617	446 366/553	584* 424/640	497 389/585	578 462/644	487 408/543	503 452/643	485 431/507	529 389/585	503 407/653	518 472/609	484 389/565	562* 451/636
Difference	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI, c. un	28.7 20/35	13.1* 8/19	23.4 18/34	12.1* 9/19	25.8 16/37	13.9* 8/21	25.7 17/37	16.8* 10/19	26.9 22/35	16.,1 12/28	21.3 16/41	14.2* 10/19	25.8 17/38	13.7* 10/20
Difference.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: * - the differences between the months and, in general, for the entire preparatory period between the groups of athletes are statistically significant, p< 0,05; the numbers in the "Difference" lines reflect the month with which the indicator in this month of the preparatory period differed statistically significantly (p < 0.05, according to the Mann-Whitney criterion) from the indicators of other months of this period, and the dash indicates that there are no differences. The interpretation of HRV indicators is given in the section "Research methods"; -c. un - conventional units; b/min - beats per minute.

Table 2: Median, 25 and 75 values of spectral and temporal indicators of clino- HRV in an elite skier in the presence of training loads (June 2019, June 2020) and in the absence of loads (April, June, August and October 2024).

Load Volume and Indicators BCP	HRV in the Presence of Training Loads		HRV Under Conditions of Complete Cessation of Training Loads			
	6/1/2019 (1st Point)	June 2020 (2nd Point)	April 2024 (3rd Point)	6/1/2024 (4th Point)	August 2024 (5th Point)	October 2024 (6th Point)
Load volume TDE 1-5	TDE $_{1-5}$ - 211.5 (166/269)	TDE $_{1-5}$ -101,0 (85/118)	1 month without load	3 months without load	5 months without load	7 months without load
TP, мс^2	9764 6958/10789	7559 6568/8617	$5984^{1,2}$ 5271/7187	59921 5164/8019	$3592^{1,2,3,4}$ 3100/4742	$3682^{1,2,3,4}$ 2957/3727
APHF, мс^2	3959 3161/4962	3702 3130/3970	$2653^{1,2}$ 2334/2912	$2680^{1,2}$ 2105/2827	$1380^{1,2,3,4}$ 1108/1885	$1141^{1,2,3,4,5}$ 874/1267
APVLF, мс^2	3333 2367/3968	17691 1271/2222	18361 1157/2543	$2814^{2,3}$ 2160/3323	$1400^{1,4}$ 964/1753	$1587^{1,4}$ 1040/2310
APLF, мс^2	2188 1443/3132	1930 1466/2181	1594 1205/1872	$1110^{1,2,3}$ 907/1311	$694^{1,2,3,4}$ 600/912	$752^{1,2,3,4}$ 564/883
HF, %	41 33/46	49.31 42/53	40.92 36/48	39.32 34/46	39.62 31/45	$31^{2,3,4,5}$ 21/39
VLF, %	35.4 30/43	24.11 20/27	29.4 24/36	$39.5^{2,3}$ 34/50	$39.7^{2,3}$ 30/50	$40.8^{2,3}$ 38/63
LF, %	21.1 19/24	25 21/28	25.9 20/30	$16.9^{2,3}$ 13/22	$19.8^{2,3}$ 17/22	21.13 15/25
APLF/APHF, c. un .	0.61 0.44/0.83	0.51 0.41/0.58	0.63 0.45/0.80	0.423 0.33/0.57	0.51 0.40/0.74	$0.63^{2,4,5}$ 0.56/0.83
RRNN, мс	1452 1374/1484	1483 1454/1528	$1322^{1,2}$ 1247/1357	$1272^{1,2}$ 1219/1324	$1258^{1,2,3}$ 1229/1285	$1197^{1,2,3,4,5}$ 1148/1241
HR, beat/min	41.3 40/43	40.5 39/41	$45.4^{1,2}$ 44/48	$47.1^{1,2}$ 45/49	$47.7^{1,2,3}$ 46/48	$50.1^{1,2,3,4,5}$ 48/52

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pNN50, %	70.3 69/75	68.5 65/72	66.41 64/70	68.1 60/70	50.7[1, 2, 3, 4] 46/59	45.4[1, 2, 3, 4, 5] 36/47
RMSSD, мс	119 108/132	1001 91/108	1001 91/102	91[1, 2] 79/96	64[1, 2, 3, 4] 58/75	58[1, 2, 3, 4] 52/63
SDNN, мс	101.5 90/111	761 68/87	801 75/87	77.51 72/87	59[1, 2, 3, 4] 56/69	58[1, 2, 3, 4] 53/62
MxDMn, мс	605 557/655	3671 342/451	464[1,2] 379/522	4071 373/456	304[1,2,3,4] 279/332	305[1,2,3,4] 279/322
SI, c. un	11.2 10/14	22.11 17/25	21.31 17/28	25.41 20/27	43.3[1, 2, 3, 4] 36/50	49,0[1, 2, 3, 4] 42/52

Noted: [1] - uppercase numbers indicate the month with which the indicator in this month differs statistically significantly (according to the Mann-Whitney criterion, $p < 0.05$) from the indicators of other months; TDE $_{1-5}$ - total duration of exercise, minutes/day, including aerobic loads (working pulse of zones 1-3) and anaerobic loads ((working pulse of zones 4 and 5).

Table 3: HRV values for elite ski racer K.D. after 7 months of absence of training loads in comparison with HRV indicators for non-athletes (women); male and female Neurosoft office staff and male -contractors

Clino-HRV indicators	Ski racer K.D. October 2024 (7 months without load)	Not athletes, women [10]	Non-athletes (employees of Neurosoft, men and women) [11]	Male contractors [11]
TP, мс^2	3682	-	1684	2815
APHF, мс^2	1141	-	528	1010
HF, %	31	-	-	36.1
APVLF, мс^2	1587	-	476	744
VLF, %	40.8	-	-	33.4
AMLF, мс^2	752	-	437	745
LF, %	21.1	-	-	24.4
APLF/APHF, c. un.	0.63	-	0.81	0.85
RRNN, мс	1197	860	980	914
HR? beat/min	50.1	71.2	-	65.5
pNN50, %	45.4	36.7	13.3	31
RMSSD, мс	58	79.5	34	48.6
SDNN, мс	58	75	41	53.9
MxDMn, мс	305	432	-	-
SI, c. un .	49	54.8	-	-

Note: the dash is the absence of data; the interpretation of HRV indicators is given in the section "Research methods".

A comparison of the HRV values of a skier K.D. jumper recorded in October 2024 with similar HRV indicators of non-athletes whose cardiontervalography was recorded in clinostasis using an intervalocardiograph of the same brand (Neurosoft) as in our study showed (Table 3) that, indeed, even in October 2024, the synthesis of NN-ACh takes place, although its level is much lower than in the presence of training. Such a comparison was carried out with data on non-athletes with clino-HRV (university students), in whom clino-HRV was registered in both phases of the menstrual cycle [10], as well as with data on 25-year-old male contractors [11] and 29-year-old employees of the firm "Neurosoft" (men and women) [11]. When comparing with the data from [10], it was found (Table 3), that, judging by the values of four indicators (RRNN, HR, pNN50 and SI), reflecting the activity of PD of ANS and probably the synthesis of NN-ACh, in the skier K.D. the synthesis of NN-ACh persists even 7 months after the cessation of training In particular, the median of RRNN and of pNN50% in K.D. were higher than in women (1197 ms versus 860 ms and 45.4% versus 36.7%, respectively), and the medians of HR and of SI were lower than in women (50.1 beats per minute versus 71.2 beats per

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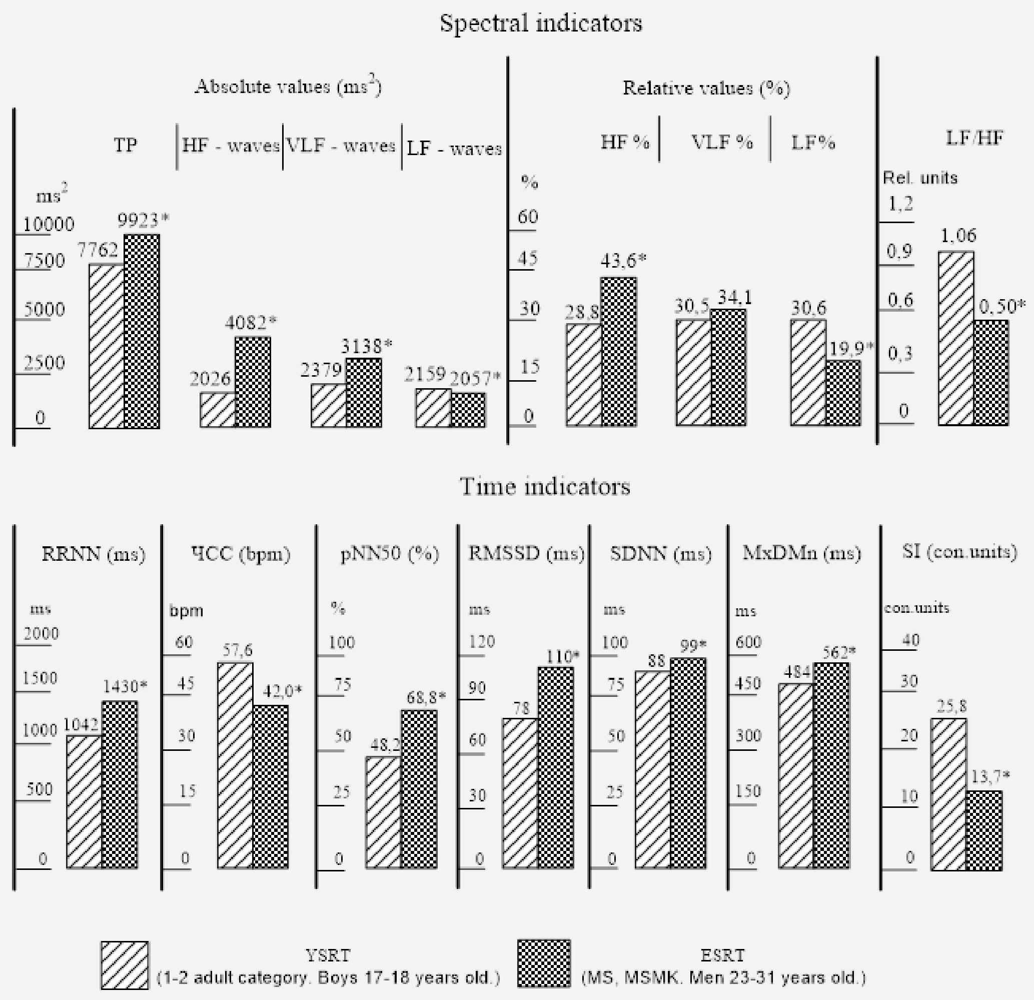
minute, respectively, and 49 c. ub. against and 54.8 c. un. However, K.D compared to women had lower values of such indicators as MxDMn (305 ms versus 432 ms), SDNN (58 ms versus 75 ms), и RMSSD (58 ms versus 79.5 ms). This indicates a lower activity of PD of ANS and, consequently, a low level of synthesis NN-ACh by cardiomyocytes in K.D. (October 2024). When compared with the data [11] obtained during the examination of contract workers (Table 3) it was shown that their values of a number of indicators (APHF, HF%, APLF, LF%, RMSSD, SDNN) were approximately the same as those of athlete K.D. (October 2024). Indeed, the value of APHF for contractors was 1010 ms2, for K.D. - 1141 ms2; the value of HF% value, respectively, 36.1% and 31.0%; the value of APLF value, respectively, 745 ms2 and 752 ms2; the value of LF%, respectively, 24.4% and 21.1%; the value of RMSSD, respectively, 48.6 ms and 58 ms; the value of SDNN -53.9 ms and 58 ms, respectively However, the values of such indicators as TP, VLF, VLF%, pNN50% for K.D. were significantly higher, and the values of heart rate was lower than for contractors. Indeed, the TP values for K.D. were 3682 ms2 versus 2815 ms2 for contractors; for values of APVLF, respectively, 1586 ms2 versus 744 ms2, for values of VLF%, respectively, 40.8% versus 33.4%; for values of RRNN, respectively, 1197 ms versus 914 ms; for values of pNN50%, respectively, 45.4% versus 31%; for values of HR, respectively, 50.1 versus 65.5 beats/min. All this suggests that 7 months after the cessation of training, in the athlete K.D. retains the synthesis of NH-ACh, although its level is much lower than that of the during his training.



Note: the symbol * means that the differences between the groups are statistically significant according to the Mann – Whitney criterion, $p < 0.05$; interpretation of HRV indicators is given in the section "Research methods".

Figure 1: Medians of clінщ-HRV indicators for YSRT and ESRT (in general, for the entire preparatory period), including TP (mc2), absolute power of HF, VLF, and LF waves (mc2), relative (in% to TP) power of these waves, the ratio APLF/APHF, as well as RRNN (ms), heart rate (bpm), pNN50% (%), RMSSD (ms), SDNN ms), MxDMn (ms), SI (c. units).

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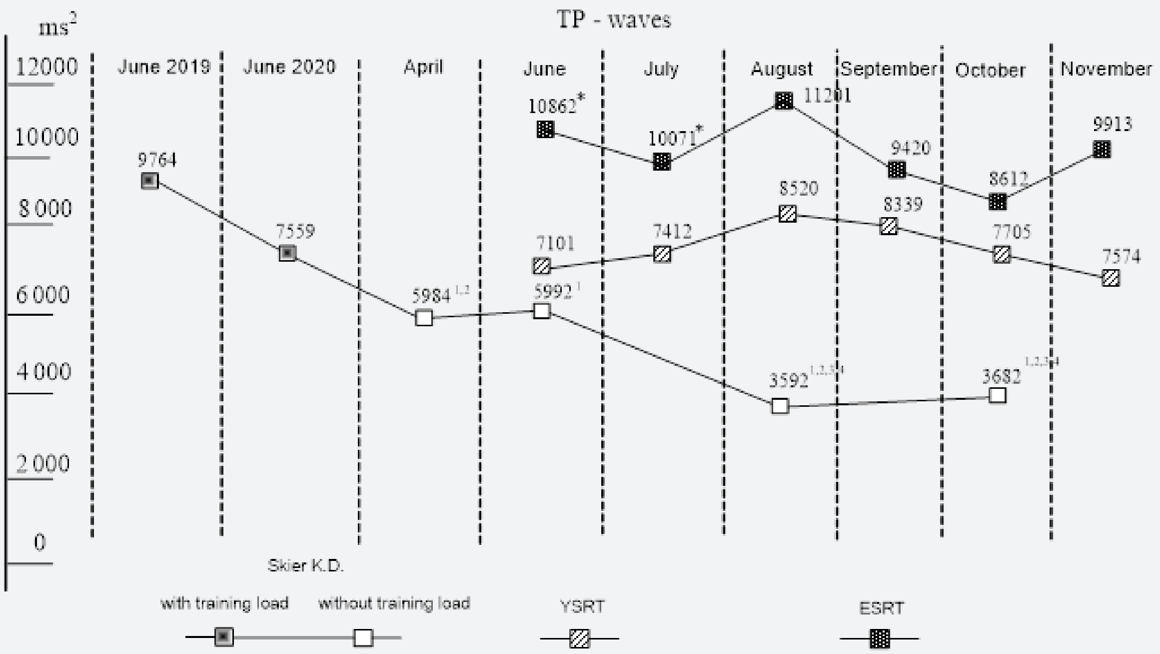
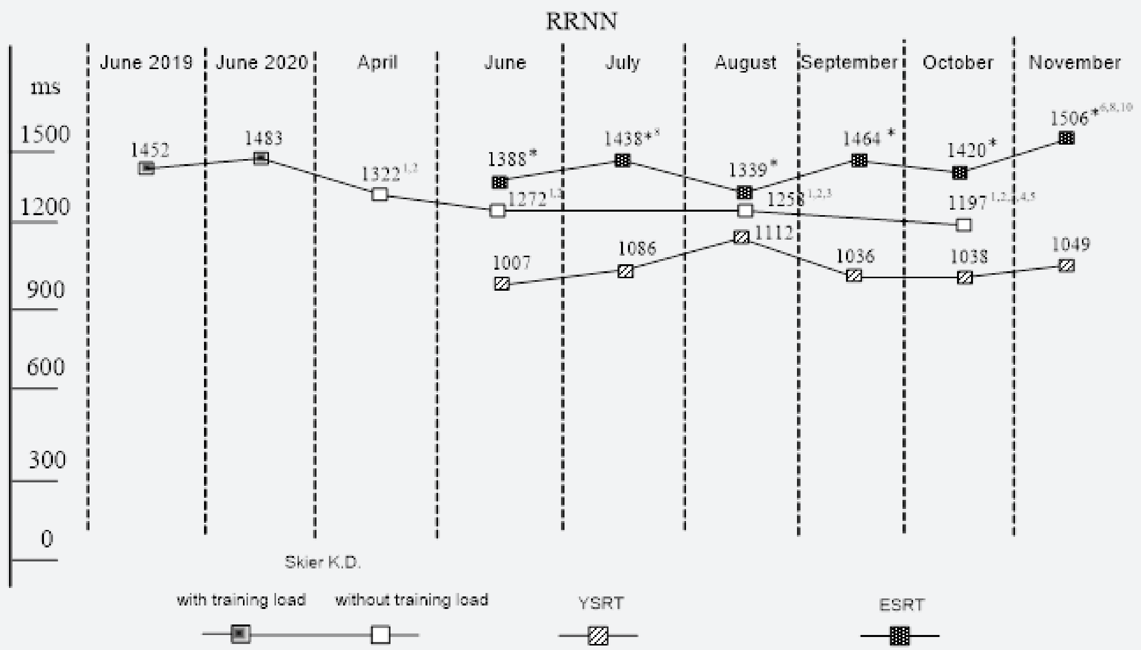


Note: 1) the symbol * means that the difference between ESRT and YSRT is statistically significant according to the Mann–Whitney criterion, $p < 0.05$;
2) the uppercase numbers in K.D. mean that the differences between the months (1 – June 2019, 2 – June 2020, 3 – April 2024, 4 – June2024, 5 – August 2024) – statistically significant (according to the Mann–Whitney criterion, $p < 0.05$).

Figure 2: Medians of the absolute TP-wave power (mc2) according to clinostatic cardiointervalography for YSRT (outlined squares), ESRT (dark squares) during the 6 months of the preparatory period, as well for K.D. under training loads, i.e., in June 2019 and June 2020 (partially dark squares) and with a 7-month absence of training (light squares).



The notes are the same as in Figure 2.
Figure 3: Medians of RRNN (ms) according to clinostatic cardiointervalography data for YSRT (outlined squares), ESRT (dark squares) during the 6 months of the preparatory period, as well as for K.D. under training loads, i.e., in June 2019, in June 2020 (partially dark squares) and with a 7-month absence of training (light squares).

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Compared with the data [11-14] obtained during the survey of Neurosoft employees, it is shown (Table 3) that the values of TP, APHF, APLF, APVLF, RRNN, pNN50%, RMSSD, SDNN were higher in K.D, and the value of APLF/APHF is lower than that of the company's employees. Indeed, the values for TP in the K.D, remained 3682 ms2 versus 1684 ms2 for the company's employees; for APHF - 1141 ms2 versus 528 ms2, respectively; for APLF 752 ms2 versus 437 ms2, respectively; for APVLF - 1587 ms2 versus 476 ms2; for RRNN- 1197 versus 980 ms, respectively; for pNN50% - 45.4% versus 13.3%, respectively; for RMSSD, 58 ms versus 34 ms, respectively; for SDNN - 58 ms versus 41 ms, and for the APLF/APHF- respectively - 0.63 c.un versus 0.81 c.un ,This also suggests that even 7 months after the cessation of training loads, in athlete K.D. synthesis of NN-ACh persists, although at a lower level than in the presence of training. In general, it can be concluded that in the absence of stimuli that cause synthesis of NN-Ach, for example, accumulation of reactive oxygen species (ROS), or myocardial damage, the synthesis of NN-ACh in elite skiers gradually decreases.At the same time, our data demonstrate that regular physical activity is necessary to maintain athletic vagotonia, including the presence of synthesis of f NN-Ach by cardiomyocytes. It is obvious that the regression of sports vagotonia does not occur instantly, but gradually, as the duration of relative inactivity increases, i.e., the absence of systematic endurance training loads.

Conclusions

Among elite cross-country skiers of the Republic of Tatarstan (RT) , or ESRT (MS, MSIC), in comparison with young cross-country skiers of the Republic of Tatarstan, or YSRT, the medians of 14 indicators of clino-HRV differed, while 9 of them, reflecting mainly the activity of PD of ANS, were higher (TP, APHF, APVLF, HF%, RRNN, pNN50%, RMSSD, SDNN, MxDMn), and 5 indicators, reflecting the activity of SD of ANS were lower (APLF, LF%, APLF/APHF, HR, SI), and only the median of one indicator did not differ (VLF%).This confirms the idea of sports vagotonia as a result of activation of the parasympathetic division (PD) of the autonomic nervous system (ANS) and, probably, increased synthesis of non-neuronal acetylcholine (NN-ACh) by cardiomyocytes of the ventricles of the heart, which occurs as the experience and qualifications of endurance athletes increase.

During the preparatory period, which lasts six months, the medians of 9 clino- HRV indicators change in ESRT, of which the medians of HF% and of RRNN increase, and the medians of APHF, APVLF, VLF%, APLF, APVLF/APHF, HR and RMSSD decrease, while the medians of the remaining 6 indicators (TP, LF%, pNN50%, SDNN, MxDMn, SI) do not change. Consequently, during the 6-month preparatory period, ESRT retains a high activity of PD of ANS and, probably, a high level of synthesis of NN-ACh, while in conditions of clinostasis, the high activity of SD of ANS, which is typical for elite skiers in competition conditions, does not significantly affect on the indicators of clino-HRV, which is likely it is explained by the inhibitory effect of PD of ANS and NN-ACh

Unlike ESRT at YSRT only medians of 3 indicators (from of 15) of clino-HRV change during the preparatory period - median of HF% decreases, and the medians of LF% and APLF/APHF - increasing. This suggests that the activity of PD of ANS and, probably, the level of NN-Ach synthesis during the preparatory period in YSRT remains stable, but lower than in ESRT, and also that in conditions of clinostasis in YSRT the ability of PD and NN-ACh is probably insufficient to inhibit SD of ANS.

The difference in changes in the medians of clino-HRV in ESRT and YSRT during the preparatory period indicates a significant difference in the mechanisms of regulation of cardiac activity between these groups, which is probably due to a higher level of synthesis of NN-ACh in elite skiers. The revealed difference also indicates that the formation of sports vagotonia, i.e., an increase in activity PD of ANS and synthesis of NN-ACh occurs gradually over many years under conditions of continuous training process

In an elite skier, after 7 months from the moment of forced cessation of training loads, the medians of 10 indicators of clinical HRV (TP, APHF, HF%, APVLF, APLF, RRNN, pNN50%, RMSSD, SDNN, MxDMn) decrease statistically significantly; the medians of 3 indicators (VLF%, HR, SI) increase, and only the medians of the 2 indicators (LF%, APLF/APHF) do not change. It has been shown that with an increase in the "off-load" period, the effect of PD of ANS on heart function decreases in an elite skier and, probably, decreases the intensity of NN-ACh synthesis.

However, even 7 months after the cessation of training, the synthesis of NH-ACh in an elite skier is probably still preserved, albeit at a lower level. This is confirmed by the fact that in October 2024 (the last month of follow-up), the medians of 4 HRV- indicators (LF%, APLF/APHF, RRNN, HR) were between the medians of the corresponding ESRT and YSRT indicators, although the median of 9 HRV-indicators (TP, APHF, HF%, APVLF, APLF, pNN50%, RMSSD, SDNN, MxDMn) were lower in K.D. and the median SI was higher than in ESRT and YSRT. The partial preservation of the synthesis of NN-ACh in the elite skier K.D. (October 2024) is also evidenced by the results of comparison with literature data on the values of HRV indicators in non-athletes.

In general, the results of the study allow us to conclude that the regression of sports vagotonia in the conditions of complete absence of training loads occurs over the course of 7 months, i.e., much faster than the formation of sports vagotonia, which takes many years.

The Authors' Contribution to the Publication

S D.A. Kataev - registration of a cardio interval gram (CIG) in the field, analysis of its parameters, writing an article, literature analysis; V.I. Tsikin - head of scientific work, literature analysis,

work on the article; S.I. Trukhina, A.N. Trukhin - scientific editing, preparation of the article and the necessary documentation

Ethical Standards

All studies were conducted in accordance with the principles of biomedical ethics formulated in the Helsinki Declaration of 1964 and its subsequent updates and approved by the local Bioethical Committee of Vyatka State University (Kirov). (Protocol No. 1, dated 17.01.2020).

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