UDC 613.65:612.172/.173:797.2
DOI: 10.14739/2310-1210.2021.5.237403

Original research

Effect of long-term training on heart rate variability, central hemodynamics and physical working capacity in female swimmers with different sports qualifications

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A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation; D – writing the article; E – critical revision of the article; F – final approval of the article

The aim of this study was to compare the indices of heart rate variability, central hemodynamics and physical working capacity in female swimmers with different sports qualifications.

Materials and methods. The indices of heart rate variability (HRV), central hemodynamics (CH) and physical development (PD) were studied in 44 female swimmers (mean age 15.00 ± 0.36 years, swimming experience – 7.40 ± 0.35 years) depending on their sports qualifications (MSIC, MS, CMS, first- and second-class athletes). To analyze the autonomic regulation of cardiac activity, power spectral and time-domain indices of HRV were used. CH were examined by the method of automated tetrapolar rheography according to W. Kubiček et al. (1970) in Y. T. Pushkar's et al. modification (1970). Physical working capacity was measured according to the generally accepted technique on a cycling ergometer using the PWC_{170} submaximal test. The functional state index (FSI) was calculated using the formula patented by authors.

Results. Significant differences were found between the indices of HRV, CH and PD in female swimmers with different qualifications. Thus, in the athletes with the MSIC–MS sports qualifications, heart rate was 61.0 ± 3.8 bpm, cardiac index (CI) – 2.978 ± 0.098 $L \cdot min^{-1} \cdot m^{-2}$ (there was a trend towards the eukinetic type of hemodynamics (TH)), stress index (SI) – 51.16 ± 12.66 relative units (r.u.), $PWC_{170/kg}$ – 16.98 ± 1.22 $kgm \cdot min^{-1} \cdot kg^{-1}$, FSI – 6.511 ± 0.422 r.u. A decrease in heart rate among them was correlated with a decrease in SI, and an increase in Mo – with a decrease in CI. In female CMS swimmers, heart rate was 61.37 ± 2.83 beats/min^{-1}, CI – 3.021 ± 0.112 $l^{-1} min^{-1} \cdot m^{-2}$, a trend towards the predominantly eukinetic TH, SI – 53.73 ± 9.41 r.u., $PWC_{170/kg}$ – 14.66 ± 0.683 $kgm \cdot min^{-1} \cdot kg^{-1}$, FSI – 5.683 ± 0.324 r.u. Reduced values of SI and CI were associated with increased values of Mo and $PWC_{170/kg}$. In first- and second-class female swimmers, heart rate was 63.05 ± 2.22 beats/min, SI – 50.62 ± 6.4 r.u. This group tended to be eytonic and eukinetic. The mean value of the $PWC_{170/kg}$ was 14.19 ± 0.589 $kgm \cdot min^{-1} \cdot kg^{-1}$ and FSI – 5.953 ± 0.337 r.u. Correlation analysis confirmed the relationship between the decrease in heart rate and CI and the increase in Mo and $PWC_{170/kg}$.

Conclusions. Long-term training in female swimmers at the distance of 50 to 200 meters is accompanied by the significant increase in the $PWC_{170/kg}$ values with qualification improving, 14.19 ± 0.589 $kgm \cdot min^{-1} \cdot kg^{-1}$, 14.66 ± 0.683 $kgm \cdot min^{-1} \cdot kg^{-1}$; 16.98 ± 1.22 $kgm \cdot min^{-1} \cdot kg^{-1}$, respectively, improvements in HRV (decrease in stress index and increase in Mo) and decrease in CI.

Key words: swimming, female, athletes, correlation.

Zaporozhye medical journal 2021; 23 (5), 621-627

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Вплив довготривалих тренувань на варіабельність серцебиття, центральну гемодинаміку та фізичну працездатність жінок-плавців із різними спортивними кваліфікаціями

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Мета роботи – порівняти показники варіабельності серцевого ритму, центральної гемодинаміки та фізичної працездатності у представниць плавання на короткі дистанції, які розрізняються за кваліфікацією.

Матеріали та методи. Вивчили показники варіабельності серцевого ритму (ВСР), центральної гемодинаміки (ЦГ) і фізичної працездатності (ФП) у 44 плавчих (середній вік – 15,00 ± 0,36 року, стаж занять плаванням – 7,40 ± 0,35 року) залежно від спортивної кваліфікації (МС–МСМК, КМС, I–II розряд). Для аналізу вегетативної регуляції серцевої діяльності використовували часові та спектральні показники ВСР. Центральну гемодинаміку вивчали методом автоматизованої тетраполярної реографії за W. Kubiček et al. (1970) в модифікації Ю. Т. Пушкаря та співавт. (1970). Визначення фізичної працездатності здійснювали за загальноприйнятою методикою на велоергометрі з використанням субмаксимального тесту PWC_{170}. Індекс функціонального стану (ІФС) розрахували за запатентованою авторами формулою.

Результати. Виявили вірогідні відмінності між показниками ВСР, ЦГ і ФП у представниць плавання, які розрізнялися за кваліфікацією. Так, у плавців-жінок рівня МС–МСМК ЧСС була 61,0 ± 3,8 уд./хв, СІ – 2,978 ± 0,098 $л \cdot хв^{-1} \cdot м^{-2}$ (була тенденція до переважання еукінетичного ТК), ІН – 51,16 ± 12,66 ум. од., $PWC_{170/кг}$ – 16,98 ± 1,22 $кгм \cdot хв^{-1} \cdot кг^{-1}$, ІФС – 6,511 ± 0,422 відн. од. Зменшення частоти серцевих скорочень у них корелює зі зменшенням ІН, а збільшення Мо – зі зниженням СІ. Плавці-жінки кваліфікації КМС мають ЧСС 61,37 ± 2,83 $уд \cdot хв^{-1}$, СІ – 3,021 ± 0,112 $л \cdot хв^{-1} \cdot м^{-2}$, тенденцію до переважання еукінетичного ТК, ІН – 53,73 ± 9, 41 ум. од., $PWC_{170/кг}$ – 14,66 ± 0,683 $кгм \cdot хв^{-1} \cdot кг^{-1}$, ІФС – 5,683 ± 0,324 відн. од. Зниження ІН і СІ асоціюється зі збільшенням Мо і $PWC_{170/кг}$. У плавчих кваліфікації II–I розряд ЧСС – 63,05 ± 2,22 $уд \cdot хв^{-1}$, ІН – 50,62 ± 6,4 ум. од., була тенденція до переважання ейтонії та еукінетичного типу кровообігу, $PWC_{170/кг}$ – 14,19 ± 0,589 $кгм \cdot хв^{-1} \cdot кг^{-1}$, ІФС – 5,953 ± 0,337 відн. од. Кореляційний аналіз підтвердив асоціацію зниження ЧСС і СІ зі збільшенням Мо і $PWC_{170/кг}$.

Ключові слова: плавання, жінки, спортсмени, кореляція.

Запорізький медичний журнал. 2021. Т. 23, № 5(128). С. 621-627

Висновки. Багаторічні тренування представниць плавання на дистанції від 50 до 200 метрів зі зростанням спортивної кваліфікації супроводжуються вірогідним збільшенням показників фізичної працездатності ($PWC_{170/кг}$ – 14,19 ± 0,589 кгм·хв$^{-1}$·кг$^{-1}$; 14,66 ± 0,683 кгм·хв$^{-1}$·кг$^{-1}$; 16,98 ± 1,22 кгм·хв$^{-1}$·кг$^{-1}$), позитивними зрушеннями ВСР (зниженням індексу напруги та збільшенням Mo) і зниженням СІ.

Ключевые слова: плавание, женщины, спортсмены, корреляция.

Запорожский медицинский журнал. 2021. Т. 23, № 5(128). С. 621-627

Влияние длительных тренировок на вариабельность сердечного ритма, центральную гемодинамику и физическую работоспособность пловчих разной спортивной квалификации

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Цель работы – сравнить показатели вариабельности сердечного ритма, центральной гемодинамики и физической работоспособности у представительниц плавания на короткие дистанции, которые различаются по квалификации.

Материалы и методы. Изучены показатели вариабельности сердечного ритма (ВСР), центральной гемодинамики (ЦГ) и физической работоспособности (ФР) у 44 представительниц плавания (средний возраст – 15,00 ± 0,36 года, стаж занятий плаванием – 7,40 ± 0,35 года) в зависимости от спортивной квалификации (МС–МСМК, КМС, I–II разряд). Для анализа вегетативной регуляции сердечной деятельности использовали временные и спектральные показатели ВСР. Центральную гемодинамику изучали методом автоматизированной тетраполярной реографии по W. Kubiček et al. (1970) в модификации Ю. Т. Пушкаря и соавт. (1970). Определение физической работоспособности осуществляли по общепринятой методике на велоэргометре с использованием субмаксимального теста $PWC_{170.}$ Индекс функционального состояния (ИФС) рассчитывали по запатентованной авторами формуле.

Результаты. Выявлены достоверные различия между показателями ВСР, ЦГ и ФР у пловчих, которые различаются по квалификации. Так, у пловцов-женщин уровня МС–МСМК ЧСС была 61,0 ± 3,8 уд./мин, СИ – 2,978 ± 0,098 л·мин$^{-1}$·м$^{-2}$ (имелась тенденция к превалированию эукинетического ТК), ИН – 51,16 ± 12,66 усл. ед., $PWC_{170/кг}$ – 16,98 ± 1,22 кгм·мин$^{-1}$·кг$^{-1}$, ИФС – 6,511 ± 0,422 отн. ед. Уменьшение ЧСС у них коррелирует с уменьшением ИН, а увеличение Mo – со снижением СИ. Пловчихи квалификации КМС имеют ЧСС 61,37 ± 2,83 уд.·мин$^{-1}$, СИ – 3,021 ± 0,112 л·мин$^{-1}$·м$^{-2}$, тенденцию к превалированию эукинетического ТК, ИН – 53,73 ± 9,41 усл. ед, $PWC_{170/кг}$ – 14,66 ± 0,683 кгм·мин$^{-1}$·кг$^{-1}$, ИФС – 5,683 ± 0,324 отн. ед. Снижение ИН, СИ ассоциируется с увеличением Mo и $PWC_{170/кг}$. У пловцов-женщин квалификации II–I разряд ЧСС – 63,05 ± 2,22 уд./мин, ИН – 50,62 ± 6,4 отн. ед., была тенденция к превалированию эйтонии и эукинетического типа кровообращения, $PWC_{170/кг}$ – 14,19 ± 0,589 кгм·мин$^{-1}$·кг$^{-1}$, ИФС – 5,953 ± 0,337 отн. ед. Корреляционный анализ подтвердил ассоциацию снижения ЧСС и СИ с увеличением Mo и $PWC_{170/кг}$.

Выводы. Многолетние тренировки представительниц плавания на дистанции от 50 до 200 метров с ростом спортивной квалификации сопровождаются достоверным увеличением показателей физической работоспособности ($PWC_{170/кг}$ – 14,19 ± 0,589 кгм·мин$^{-1}$·кг$^{-1}$; 14,66 ± 0,683 кгм·мин$^{-1}$·кг$^{-1}$; 16,98 ± 1,22 кгм·мин$^{-1}$·кг$^{-1}$), позитивными сдвигами ВСР (снижением индекса напряжения и увеличением Mo) и снижением СИ.

A desire of scientists (teachers, doctors, biologists) to turn the training into a controlled process is one of the characteristic features of modern sports training. It is a well-known fact that significant fluctuations in the level of the body functional state associated with adaptation to physical activity are possible in this process. An assessment of the body regulatory system is instrumental in diagnosing altered regulation, as violated functional state, in some cases, is the only criterion of the compensatory-adaptive activity of body systems [11,14], as evidenced by a close relationship between the degree of regulatory system stress, hemodynamic heterogeneity of the heart and blood pressure. All the above is very important for health management and predicting the risk of developing diseases in athletes, depending on the initial degree of the body regulatory system activity.

The relationship between hemodynamic indices, physical working capacity and the stress degree of autonomic regulation mechanisms was studied in skiers and wrestlers [3], high-class female swimmers [4], female sprinters [2], male sprinters [5], middle-distance male runners [6], middle distance female runners [7], football players [8], short-distance male swimmers [9].

There are some works on the study of the pedagogical aspects in training women involved in swimming. Thus, Evelin Maestu et al. [16] conducted a regression analysis of the survey data of 26 female swimmers with a training experience of 3.7 ± 1.8 years and duration of training 6.2 ± 1.9 hours per week and concluded that swimming results at a distance of 400 meters are best characterized by biomechanical factors, followed by bioenergetics and physical indices. Examining female swimmers aged 10.4 ± 0.6 to 19.9 ± 4.6 years, Tsalis Georgios et al. [17] indicated earlier fatigue in young and adult swimmers due to decreased stroke length. Antonio Jose Silva et al. [18] identified an overall upward trend in the rate of sports results among female swimmers aged 11–12 years and 14–16 years, which was explained not only by the training process, but also by the growth, development and maturation process.

A few scientific papers have demonstrated the medical and biological aspects of the training load influence on female swimmers. For example, A. E. Bolotin and O. E. Ponimasov [15] have suggested that the main indicator of the training level is the nervous and hormonal component influence on the synchronization of heart rate regulation. The high degree of heart rate regulatory component synchronization was indicative of physical load adequacy in respect of the body adaptive reactions in female athletes. The authors believe that heart rate variability (HRV) in female athletes depends on the coordinated functioning of the nervous and hormonal regulatory systems. According to the authors, a decrease in the indicators of heart rate hormonal regulation indicates a decrease in the adaptive abilities of the body; central regulation of the cardiac activity under stressful effects of the training load demonstrates the imbalance between the processes of energy assimilation and dissimilation; inadequacy of the nervous and hormonal regulation for heart rhythm leads to a decrease in the adaptive capacities in athletes.

Our previous work [4] has shown favorable changes in HRV among female swimmers with MSIC–MS qualifications and no differences in indices of central hemodynamics (CH) and physical performance compared to female athletes with CMS qualification, which was confirmed by correlation analysis. However, the question of the effect of long-term physical activity on HRV, CH and physical development (PD) among female swimmers at a distance of 50–200 meters, depending on their sports qualifications, requires further study.

Aim

The aim of the study was to compare the indices of HRV, CH and physical working capacity in female short-distance swimmers with different sports qualifications.

Materials and methods

At the beginning of the preparatory period, a comprehensive examination was carried out, including the measurements of anthropometric parameters, HRV, indices of CH and physical working capacity in 44 female swimmers (mean age 15.00 ± 0.36 years, swimming experience – 7.40 ± 0.35 years) at a distance of 50 to 200 meters with a sports qualification from second-class to Master of Sports of International Class (MSIC).

To evaluate the autonomic regulation of cardiac activity, mathematical methods for analysis of HRV parameters were used: mode (Mo, s), mode amplitude (AMo, %), variation range (D, s). A number of derived indices were calculated: autonomic equilibrium index (AMo/D, %/s), autonomic rhythm index (ARI, $1/s^2$), adequacy of regulation processes (ARP, %/s), stress index (SI, r.u.). The frequency HVR components were assessed analyzing the spectral indicators of autocorrelation functions: total spectral power (TP) (ms^2), spectral components of the very low frequency (VLF) (ms^2), low frequency (LF) (ms^2) and high frequency (HF) (ms^2), LF and HF normalized values (LFn, %, HFn, %), LF/HF ratio (r.u.). CH was examined by the method of automated tetrapolar rheography according to W. Kubiček et al. (1970) in Y. T. Pushkar's et al. modification (1970). Stroke volume (SV) and cardiac output (CO), stroke volume index (SVI) and cardiac index (CI), systemic vascular resistance (SVR) and systemic vascular resistance index (SVRI) were calculated. Physical working capacity was measured according to the generally accepted technique on a cycle ergometer using the PWC_{170} submaximal test [12] with further calculation of the relative value of physical working capacity ($PWC_{170/kg}$). The functional state index (FSI) was calculated according to the formula proposed and patented by the authors [10].

Statistical analysis was performed with Statistica for Windows 13 (StatSoft Inc., No. JPZ804I382130ARCN10-J). All the data were expressed as means (M) ± the standard error (m). The significance of mean differences was analyzed by two-tailed t-test for independent samples. Differences between two subsets of data were considered statistically significant at a level of P (P-value) less than 0.05. Pairwise Pearson correlation was used to analyze the association between HRV, CH and physical working capacity indices.

Results

In the group of female swimmers (n = 44), anthropometric measures were: body height – 167.0 ± 0.99 cm, body weight – 57.2 ± 1.20 kg. Among time-domain and power spectral HRV indicators, the SI should be noted, which averaged 51.86 ± 4.98 r.u., corresponding to the state of eutonia, and the sympatho-vagal index averaged 1.334 ± 0.174 r.u., representing the normal value.

The mean HR in the group was 62.02 ± 1.57 bpm, SVI – 49.73 ± 0.94 $ml{\cdot}m^{-2}$, CI – 3.045 ± 0.064 $L{\cdot}min^{-1}{\cdot}m^{-2}$, which corresponded to the eukinetic type of hemodynamics (TH), SVR – 1314.18 ± 27.88 $dn{\cdot}s{\cdot}cm^{-5}$ and SVRI – 27.00 ± 0.654 r.u. The TH distribution in female swimmers was as follows: hypokinetic – 24.54 %, eukinetic – 56.82 % and hyperkinetic – 13.64 %, demonstrating a significant prevalence of eukinetic TH as compared to hypokinetic (P = 0.05) and hyperkinetic (P = 0.05) ones, and matching the mean CI values in the total group of female swimmers. The mean value of the relative physical working capacity was 14.93 ± 0.45 $kgm{\cdot}min^{-1}{\cdot}kg^{-1}$, and the FSI ranged 5.969 ± 0.206 r.u., corresponding to a "low" score [10].

Following the purpose of this study, all female swimmers were divided into three groups depending on their sports qualifications:

Group I (n = 9) consisted of female swimmers with sports qualifications MSIC–MS (mean age 17.4 ± 1.14 years, swimming experience 9.7 ± 1.04 years, body height –171.3 ± 2.17 cm, body weight – 63.6 ± 2.09 kg).

Group II (n = 16) consisted of female swimmers with sports qualification CMS (mean age 15.1 ± 0.40 years, swimming experience 7.4 ± 0.44 years, body height 167.5 ± 1.55 cm, body weight 57.1 ± 1.85 kg).

Group III (n = 19) included female swimmers of second- and first-class sports qualifications (mean age 13.7 ± 0.27 years, experience in swimming 6.3 ± 0.28 years, body height 166.8 ± 1.52 cm, weight 54.3 ± 1.77 kg).

Female swimmers of MS-MSIC and CMS sports qualifications were older and had longer experience in swimming than those characteristics in first- and second-class athletes (P = 0.01, P = 0.01, P = 0.007, P = 0.04, respectively). There were no significant differences in these indicators between groups I and II (P = 0.08, P = 0.07). Among the anthropometric parameters, significant differences were revealed only in body weight between groups I and II (P = 0.031), as well as between groups I and III (P = 0.003).

The time-domain and spectral indices of HVR did not differ significantly between the groups. Thus, the SI of regulatory systems was 51.16 ± 12.66 r.u. in group I, 53.73 ± 9.41 r.u. – in group II, and 50.62 ± 6.4 r.u. – in group III, being attributable to eutonia. The mean values of the sympatho-vagal index confirmed the obtained data as its value in group I was 1.059 ± 0.382 r.u., in group II – 1.674 ± 0.331 r.u., in group III – 1.178 ± 0.226 r.u.

The lowest mean HR was in group I – 61.0 ± 3.8 bpm, in group II – 61.37 ± 2.83 bpm and in group III – 63.05 ± 2.22 bpm without significant differences between the groups.

In group I, the CI was 2.978 ± 0.098 $l \cdot min^{-1} \cdot m^{-2}$, in group II – 3.021 ± 0.112 $l \cdot min^{-1} \cdot m^{-2}$, in group III – 3.098 ± 0.108 $l \cdot min^{-1} \cdot m^{-2}$ being comparable and complying with eukinetic TH. The percentage of TH in the groups was: in group I – 33.33 %: 66.67 %: 0 %, in group II – 25.0 %: 62.5 %: 12.5 %, in group III – 31.58 % : 47.37 % : 21.05 %, hypokinetic, eukinetic and hyperkinetic TH, respectively. That is, among female athletes with MS–MSIC sports qualifications, there was a marked tendency towards the prevalence of eukinetic TH (P = 0.343) in the absence of female athletes with hyperkinetic TH. In the group of female athletes with CMS sports qualification, there was a tendency towards the prevalence of eukinetic TH in comparison with hypokinetic (P = 0.204) and hyperkinetic TH (P = 0.195). Female athletes with first- and second-class sports qualifications demonstrated a tendency to the prevalence of eukinetic TH in comparison with hypokinetic (P = 0.543) and hyperkinetic TH (P = 0.370). The obtained results indicated the prevalence of female athletes with eukinetic TH in the groups and matched mean CI values of all groups, while in the group of female swimmers with MS–MSIC qualifications, there were no athletes with hyperkinetic TH, which was considered less physiologically beneficial.

Comparison of SVR and SVRI mean values revealed the absence of significant differences among swimmers differing in their sports qualifications. The relative value of physical working capacity was the highest in group I and averaged 16.98 ± 1.223 $kgm \cdot min^{-1} \cdot kg^{-1}$ as compared to that in group II – 14.66 ± 0.683 $kgm \cdot min^{-1} \cdot kg^{-1}$ (P = 0.121) and group III – 14.19 ± 0.589 $kgm \cdot min^{-1} \cdot kg^{-1}$ (P = 0.063).

The highest FSI was estimated at 6.511 ± 0.422 r.u. in group I, which corresponded to "below the average" score, compared with that in group II – 5.683 ± 0.324 r.u. and in group III – 5.953 ± 0.337 r.u., that matched "low" FSI score.

Correlation analysis of HRV, CH and physical performance indices in female swimmers (n = 44) revealed the presence of 54 significant correlations, 26 of which were positive and 28 were negative. The greatest number of correlations – 15, was found between HR, time-domain and spectral components of HRV, $PWC_{170/kg}$ and FSI.

Positive correlations were found between HR and AMo (r = 0.340, P = 0.024), HR and AMo/D (r = 0.315, P = 0.037), HR and ARI (r = 0.570, P = 0.0001), HR and ARP (r = 0.657, P = 0.0001), HR and SI (r = 0.487, P = 0.001), HR and TP (r = 0.329, P = 0.029), HR and LF (r = 0.570, P = 0.0001), HR and LF % (r = 0.570, P = 0.0001), HR and LF/HF (r = 0.570, P = 0.0001), HR and VLF (r = 0.332, P = 0.028).

Negative correlations were found between HR and Mo (r = -0.818, P = 0.0001), HR and HF (r = -0.421, P = 0.004), HR and HF % (r = -0.570, P = 0.0001), HR and $PWC_{170/kg}$ (r = -0.497, P = 0.001), HR and FSI (r = -0.364, P = 0.015). The positive correlations between HR and SI, HR and LF/HF, as well as the negative correlations between HR and Mo, HR and $PWC_{170/kg}$, HR and FSI were considered to be of the highest importance, indicating that a decrease in HR under the training process influence in female swimmers was accompanied by a decrease in SI and simpatho-vagal index and an increase in Mo – a component characterizing the level of sinus node activity and its good functional state, as well as a high relative value of physical working capacity and FSI.

A significant correlation was found between the CH and HRV indices. In particular, positive – between SVI and Mo (r = 0.418, P = 0.005), SVI and HF (r = 0.314, P = 0.038); negative – between SVI and ARI (r = -0.303, P = 0.046), SVI and ARP (r = -0.319, P = 0.035). A positive correlation was also found between CI and ARI (r = 0.411, P = 0.006), CI and ARP (r = 0.488, P = 0.001), CI and SI (r = 0.342, P = 0.023), CI and LF (r = 0.476, P = 0.001), CI and LF % (r = 0.420, P = 0.005), CI and LF/HF (r = 0.434, P = 0.003), as well as negative – between CI and Mo (r = -0.633, P = 0.0001), CI and HF % (r = -0.420, P = 0.005), CI and $PWC_{170/kg}$ (r = -0.424, P = 0.004). The data obtained were indicative of bradycardia development in female swimmers resulted from long-term training physical loads due to an increase in the Mo component and a decrease in CI to a level corresponding to the most favorable type of blood circulation, the hypokinetic one. In addition, a decrease in the SI pointed to the strengthening of vagotonia. Moreover, these shifts were associated with an increase in the physical performance in female swimmers.

Positive correlations were revealed between SVR and SRVI, and Mo (r = 0.482, P = 0.001) and (r = 0.560, P = 0.0001), respectively, HF % (r = 0.449, P = 0.002) and (r = 0.363, P = 0.016); negative – AMo (r = -0.410, P = 0.006) and (r = -0.337, P = 0.025), AMo/D (r = -0.349, P = 0.020), ARI (r = -0.476, P =0.001) and (r = -0.409, P = 0.006), ARP (r = -0.570, P = 0.0001) and (r = -0.519, P = 0.0001), SI (r = -0.458, P = 0.002) and (r = -0.370, P = 0.013, LF (r = -0.572, P = 0.0001) and (r = -0.454, P = 0.002), LF % (r = -0.449, P = 0.002) and (r = -0.363, P = 0.016), LF/HF (r = -0.502, P = 0.001) and (r = -0.423, P = 0.004). Thus, an increase in SVR and SVRI was accompanied by a decrease in SI and LF/HF in female swimmers.

As for the correlations between the studied indicators and physical working capacity, a significant positive relationship was revealed between $PWC_{170/kg}$ and Mo (r = 0.520, P = 0.0001), $PWC_{170/kg}$ and SVR (r = 0.299, P = 0.049), $PWC_{170/kg}$ and SRVI (r = 0.406, P = 0.006), as well as negative between $PWC_{170/kg}$ and LF (r = -0.290, P = 0.05), $PWC_{170/kg}$ and HR (r = -0.497, P = 0.001), $PWC_{170/kg}$ and CI (r = -0.424, P = 0.004). For FSI, a positive correlation was with Mo (r = 0.336, P = 0.026) and a negative – with ARI (r = -0.346, P = 0.021), LF (r = -0.299, P = 0.048) and HR (r = -0.364, P = 0.015).

Thus, an increase in Mo, SVR, SVRI and a decrease in LF, HR and CI indirectly indicated an increase in physical working capacity; FSI increased with an increase in Mo and a decrease in ARI and HR in female swimmers. The association between the decrease in CI, HR and the increase in physical performance in athletes was the most important to understand the adaptation process.

Correlation analysis between the studied indicators among female swimmers with MS–MSIC qualifications (n = 9) revealed 32 significant correlations, 15 of which were positive, and 17 were negative. The greatest number of correlations was with HR – 12. Thus, positive correlations were between HR and AMo (r = 0.741, P = 0.022), HR and AMo / D (r = 0.648, P = 0.05), HR and ARI (r = 0.736, P = 0.024), HR and ARP (r = 0.947, P = 0.0001), HR and SI (r = 0.784, P = 0.012), HR and LF (r = 0.674, P = 0.047), HR and LF % (r = 0.884, P = 0.002), HR and LF/HF (r = 0.793, P = 0.011), HR and VLF (r = 0.690, P = 0.04), and negative – between HR and Mo (r = -0.959, P = 0.0001), HR and HF (r = -0.736, P = 0.024), HR and HF % (r = -0.884, P = 0.002).

The positive correlations between HR and SI, HR and LF/HF, as well as the negative one between HR and Mo were considered the most important. These correlations confirmed the hypothesis that the decrease in HR under the training process influence is accompanied by a decrease in the SI, sympatho-vagal index and an increase in Mo, and showed the dominant level of the sinus node activity, namely vagotonia, associated with a favorable functional state of female swimmers.

Between the integral indicators of CH, SVI, CI and the studied indicators, 10 significant correlations were found, 7 of which were with SVI and 3 – with CI. Positive correlations were between SVI and Mo (r = 0.847, P = 0.004), SVI and HF (r = 0.755, P = 0.019), SVI and HF % (r = 0.664, P = 0.05) and negative between SVI and AMo (r = -0.679, P = 0.044), SVI and ARP (r = -0.837, P = 0.005), SVI and SI (r = -0.648, P = 0.05), SVI and LF % (r = -0.664, P = 0.05). A positive correlation was between CI and LF % (r = 0.725, P = 0.027) and negative – with Mo (r = -0.671, P = 0.048) and HF % (r = -0.725, P = 0.027). The most important was the negative correlation between CI and Mo confirming the data on a favorable decrease in the CI amid increasing Mo. Equally important was the negative relationship between the SVI and SI, showing that a decrease in the SI was accompanied by an increase in the SVI. The correlations between the CI and HRV frequency domain indices (positive with LF % and negative with HF) were accompanied by a decrease in the CI to the levels corresponding to the hypokinetic TH. A significant positive correlation was between SVR and HF % (r = 0.774, P = 0.014) and negative – with ARI (r = -0.703, P = 0.035), SI (r = -0.708, P = 0.033), TP (r = -0.671, P = 0.048), LF (r = -0.813, P = 0.008), LF % (r = -0.774, P = 0.014), LF/HF (r = -0.781, P = 0.013) and VLF (r = -0.660, P = 0.05). A negative correlation was found between SVRI and LF (r = -0.666, P = 0.05), as well as a positive one with $PWC_{170/kg}$ (r = 0.711, P = 0.032).

The number of significant correlations between studied indices in 16 swimmers with CMS qualification was 28 (14 positive and 14 negative). HR was positively correlated with ARI (r = 0.555, P = 0.026), ARP (r = 0.586, P = 0.017), LF (r = 0.533, P = 0.033), LF/HF (r = 0.498, P = 0.049), and negatively – with Mo (r = -0.873, P = 0.0001). The principal correlation was between HR and Mo, indicating that the developing bradycardia under the long-term training influence in swimming was accompanied by an increase in the Mo-component of HRV, which was indicative of a good functional state of female athletes. A positive correlations was found between the CI and ARI (r = 0.562, P = 0.024), ARP (r = 0.673, P = 0.004), SI (r = 0.537, P = 0.032), LF (r = 0.566, P = 0.022), LF % (r = 0.491, P = 0.05), LF/HF (r = 0.596, P = 0.015) and negative – with Mo (r = -0.666, P = 0.005) and HF % (r = -0.491, P = 0.05). The positive correlation between the CI and SI, CI and LF/HF, and the negative one between the CI and Mo was of the highest relevance, confirming a favorable decrease in the CI amid increased Mo, decreased SI and sympatho-vagal index.

Evaluation of the studied SVR and SVRI correlations showed the presence of a significant positive correlation between SVR and Mo (r = 0.584, P = 0.018) and a negative one with ARI (r = -0.491, P = 0.05) and ARP (r = -0.598, P = 0.014). SRVI was positively correlated with Mo (r = 0.600, P = 0.014) and negatively – with ARI (r = -0.515, P = 0.041), ARP (r = -0.615, P = 0.011) and SI (r = -0.490, P = 0.05).

A significant positive correlation was found between $PWC_{170/kg}$ and Mo (r = 0.628, P = 0.009) and negative – between $PWC_{170/kg}$ and LF/HF (r = -0.484, P = 0.05), $PWC_{170/kg}$ and HR (r = -0.697, P = 0.003). A positive significant correlation was found between FSI and Mo (r = 0.572, P = 0.021) and negative – between FSI and ARI (r = -0.542, P = 0.03), FSI and ARP (r = -0.615, P = 0.011), FSI and LF/HF (r = -0.485, P = 0.05), FSI and HR (r = -0.563, P = 0.023). The most important was the positive correlation between $PWC_{170/kg}$ and Mo, and the negative one with LF/HF and HR, indicating an increase in physical working capacity with an increase in Mo and a decrease in the SI and HR.

Correlation analysis of the studied indices in female swimmers with first- and second-class qualifications (n = 19) revealed 21 significant correlations (10 positive and 11 negative). The greatest number of correlations was found with HR. Thus, a positive correlation was with VRI (r = 0.466, P = 0.044), ARP (r = 0.559, P = 0.013), LF (r = 0.603, P = 0.006), LF/HF (r = 0.487, P = 0.034) and negative one – between HR and Mo (r = -0.693, P = 0.001), HR and HF % (r = -0.525, P = 0.021). The major correlations were between HR and LF/HF, HR and Mo, indicating a favorable decrease in the SI as HR was decreased and Mo was increased.

Regarding CH, a significant negative correlation was found between CI and Mo (r = -0.653, P = 0.002). There was a positive correlation between SVR and Mo (r = 0.547, P = 0.015) and a negative one between SVR and ARP (r = -0.552, P = 0.014), SVR and LF (r = -0.680, P = 0.001), SVR and LF % (r = -0.528, P = 0.02), SVR and LF/HF (r = -0.560, P = 0.013). A positive correlation was found between the SVRI and Mo (r = 0.640, P = 0.003) and a negative one – with LF (r = -0.442, P = 0.05).

A positive correlation was between $PWC_{170/kg}$ and Mo (r = 0.689, P = 0.004), FSI and D (r = 0.501, P = 0.029), as well as a negative correlation between $PWC_{170/kg}$ and ARI (r = -0.471, P = 0.042), $PWC_{170/kg}$ and HR (r = -0.537, P = 0.018), FSI and ARI (r = -0.471, P = 0.042).

Thus, an increase in such an important indicator in swimming, which is the relative value of physical working capacity, occurred with an increase in the Mo indicator and a decrease in ARI, and especially HR, the value of which decreased with long-term training physical loads.

Discussion

According to the works of R. M. Baevsky, system with relatively autonomous connections due to the independence of its elements is distinguished by a higher plasticity, which facilitates its adaptation to changing environmental conditions, including sports physical activity [1,13]. All this follows both the principle of economizing functions and the theory of functional systems of P. K. Anokhin, according to which a decrease in the number of links between individual elements of a functional system increases the number of “degrees of autonomy” of these elements, which contributes to the achievement of an optimal functional state when performing a certain task. Consequently, the study on the correlations allowed a better understanding the intrasystem and intersystem mechanisms of HRV regulation, the respiratory apparatus control and the body regulatory-adaptive status in athletes during the process of long-term physical loads.

Conclusions

Long-term training in female swimmers at the distance of 50 to 200 meters is accompanied by the significant increase in the $PWC_{170/kg}$ values with qualification improving, 14.19 ± 0.589 $kgm \cdot min^{-1} \cdot kg^{-1}$, 14.66 ± 0.683 $kgm \cdot min^{-1} \cdot kg^{-1}$; 16.98 ± 1.22 $kgm \cdot min^{-1} \cdot kg^{-1}$, respectively, improvements in heart rate variability (decrease in the stress index and increase in Mo) and decrease in the cardiac index.

Prospects for further research are to study further the influence of training physical loads on the indices of autonomic support of CH and physical working capacity in athletes of various sports differing in qualifications and sex.

Conflict of interest: authors have no conflict of interest to declare.
Конфлікт інтересів: відсутній.

Надійшла до редакції / Received: 23.04.2021
Після доопрацювання / Revised: 26.04.2021
Прийнято до друку / Accepted: 27.05.2021

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