Characteristics of autonomic maintenance of central hemodynamics and physical working capacity in highly qualified sprint swimmers

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Abstract

The prevalence of swimmers with hyperkinetic blood circulation and vagotonia has been noted. A tendency to apply testing to date has been explained by insufficient methodological works and lack of criteria based on modern medical and biological research.

The aim of the study was to analyze the features of the autonomic maintenance of central hemodynamics and physical efficiency in high-class sprint swimmers in the distance from 50 to 200 meters.

Materials and methods. The study compared indicators of the heart rate variability, central hemodynamics and physical working capacity in sprint swimmers with the following qualifications: Master of Sports, Master of Sports of International Class (n = 36), Candidate Master of Sports and first-class sportsman (n = 50).

Results. It has been shown that Masters of Sports and Masters of Sports of International Class in swimming are significantly older, have longer swimming experience, higher body height and weight, greater relative indices of the physical working capacity and lower heart rate in comparison with the Candidate Master of Sports and first-class sportsmen. A tendency to the prevalence of swimmers with hyperkinetic blood circulation and vagotonia has been noted.

Key words: swimming, heart rate variability, central hemodynamics, physical working capacity, correlation data.

Original research

Acknowledgements

The achievement of high sports results in swimming is largely determined by the high level of the body’s energy-related processes, as well as the ability to realize its aerobic and anaerobic potencies in conditions of overcoming competitive distances [12]. Taking into account the fact that one
of the most important systems determining the functional state of the athlete is the cardiovascular system, we examined the autonomic maintenance of central hemodynamics and physical efficiency in high-class sprint swimmers.

Aim

The aim of the study was to analyze the features of the autonomic maintenance of central hemodynamics and physical efficiency in high-class sprint swimmers.

Materials and methods

At the beginning of the preparatory period, a comprehensive examination was conducted, which included the measurement of anthropometric indices, heart rate variability (HRV), central hemodynamics and physical working capacity in 86 swimmers (average age 16.8 ± 0.30 years, swimming experience – 8.8 ± 0.27 years), specializing in the distance from 50 to 200 meters and having sport qualifications from first-class sportsman to Master of Sports of International Class (MSIC).

Mathematical methods of HRV analysis were used to analyze the autonomic regulation of cardiac activity. The following characteristics were identified: mode (Mo, s), amplitude of mode (AMo, %), and variation range (D, s).

Some derived indices were calculated: autonomic equilibrium index (AMo/E, %/s), autonomic rhythm index (ARI, 1/s²), adequacy of regulation processes (ARP, %/s), stress-index (relative units, r.u.). Analysis and estimation of frequency components of cardiac rhythm was carried out by examining spectral indices of autocorrelation functions: total power (TP) of spectrum (ms²), power in the range of very low frequencies VLF (ms²), power in the range of low LF (ms²) and high HF (ms²) frequencies, LF and HF in normalized units (LFN and HFN, %, relative units).

The analysis of the autonomous nervous system was carried out using a stress-index, an integral indicator of HRV. According to the recommendation of R. M. Bayevskiy [1], vagotonia is considered if stroke index (SI) is less than 50 r.u., euthotonia — if SI is within the range of 51–199 r.u. and sympathotonia — if SI is more than 200 r.u.

Central hemodynamics was studied 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 and cardiac output (SV, CO), SI and cardiac index (CI), systemic vascular resistance (SVR) and systemic vascular resistance index (SVRI) were calculated.

Physical working capacity was measured according to a common technique on a cycling ergometer using a submaximal PWC$_{170}$ test [13] and calculating the relative value of physical performance, i.e. PWC$_{170}$. The functional state index (FSI) was calculated according to the formula proposed and previously used by us.

The results of the study were analyzed statistically with Statistica for Windows 13 (StatSoft Inc., № JPD8041382130ARCHN10-J). All the data were presented as the sample mean (M) ± the standard error (m). The significance of average differences was analyzed by two-tailed t-test for independent samples. The difference between two subsets of data was considered statistically significant if a significance level P (P-value) was less than 0.05. Pairwise Pearson correlation was used to analyze the association between HRV, central hemodynamics and physical working capacity indices.

Results

The results of anthropometric indices measurements in swimmers showed that in the whole group, the body height was – 181.6 ± 0.87 cm, and the body weight – 70.60 ± 1.01 kg. From the time and frequency indicators of HRV, the stress index should be noted, as its average value was 54.84 ± 5.11 r.u., which corresponded to eutonia, and the sympathetic index was 1.703 ± 0.139 r.u., corresponding to its normal value.

Among the central hemodynamics indices, the mean value of HR was $58.520 ± 1.067$ bpm, SI – $49.05 ± 0.82$ ml·m$^{-2}$, CI – $2.870 ± 0.044$ l·min$^{-1}$·m$^{-2}$, SVRI – $29.44 ± 0.52$ r.u., and the average CI value corresponded to the eutonic type of circulation. The relative value of physical working capacity was $17.17 ± 0.31$ kg·min$^{-1}$·kg$^{-1}$, FSI – $6.422 ± 0.166$ r.u. Distribution of the swimmers by circulatory type (CT) showed that 43.0 %, 50.0 % and 7.0 % of the athletes were classified as hypokinetic, eukinetic and hyperkinetic CT, respectively. This showed a trend to eukinetic CT (P = 0.358) and confirmed the mean CI values.

The initial autonomic tone in the swimmers, according to the classification proposed by R. M. Bayevskiy [1], was as follows: 65.0 % – vagotonia, 33.7 % – eutonics and 1.3 % – sympathotonics. This reliably indicated the prevalence of swimmers with vagotonia (P = 0.006) and eutonics (P = 0.023) compared with sympathotonics. The FSI mean value was $6.422 ± 0.166$ units, which rated the level “below average” according to our classification.

A correlation analysis of the studied indicators revealed a positive correlation between Mo and SI (r = 0.377, P = 0.0001), Mo and SVR (r = 0.414, P = 0.0001), Mo and SVRI (r = 0.526, P = 0.0001), Mo and PWC$_{170}$ (r = 0.480, P = 0.0001), Mo and IFS (r = 0.307, P = 0.004), VPR and HR (r = 0.360, P = 0.001), VPR and CI (R = 0.312, P = 0.003), stress-index and HR (r = 0.239, P = 0.026), stress-index and CI (r = 0.259, P = 0.016), and negative – between Mo and HR (r = -0.773, P = 0.0001), Mo and CI (r = -0.466, P = 0.0001), VPR and SVR (r = -0.337, P = 0.002), VPR and SRVI (r = -0.349, P = 0.001), stress-index and SRVI (r = -0.303, P = 0.005), stress-index and SRVI (r = -0.305, P = 0.004).

Concerning the correlation of Mo, which indicates the most probable level of cardiovascular functioning, its association confirmed the fact of vagus control over the sinus node. This contributed to a decrease in HR and CI, and manifested as an economy of the circulatory system and was associated with increased physical working capacity. It is known that the autonomous rhythm index makes it possible to conclude about the autonomic balance, as the lower its value, the more the autonomic balance is shifted towards the parasympathetic regulation prevalence. In our study, the most interesting was the positive association between VPR and CI, indicating that the decrease in VPR was followed by a decrease in CI, which is energy-efficient for the athletes’ cardiovascular system.

However, the positive relationship between the stress-index and the CI (r = 0.259, P = 0.016) was the most signi-
ificant. This indicated the direct effect of the autonomous nervous system on the integral index of central hemodynamics when the decrease in the stress-index was followed by a decrease in the CI, which approximated the values of the hypokinetic type of circulation. Among the remaining indicators, there were no significant correlations.

To facilitate a correct interpretation of the data obtained, all the swimmers were divided into two groups by sports qualification.

Group I (n = 36) were Master of Sports (MS) and Master of Sport of International Class (MSIC) swimmers (average age 18.61 ± 0.41 years, experience in swimming 10.40 ± 0.44 years, body height – 186.60 ± 1.23 cm, body weight – 77.2 ± 1.36 kg).

Group II (n = 50) were Candidate Master of Sports (CMS) and first-class swimmers (average age 15.60 ± 0.33 years, experience in swimming 7.63 ± 0.23 years, body height 178.00 ± 0.92 cm, body weight 65.90 ± 0.98 kg).

When comparing anthropometric indices, it was found that the body height and weight of Group I swimmers were greater compared to Group II swimmers with a high degree of statistical significance (P = 0.00001). For most time and frequency indicators of HRV, there were no significant differences between groups. In particular, the stress-index was within the range of 51.13 ± 6.05 r.u. in Group I, and up to 57.51 ± 7.66 r.u. in Group II, which corresponded to the eutonia state. The average HR value was the lowest in Group I – 56.00 ± 1.76 bpm, compared to Group II – 60.40 ± 1.35 bpm (P = 0.047). In Group I, the average CI was 2.795 ± 0.058 L·min⁻¹·m⁻², in Group II – 2.925 ± 0.063 L·min⁻¹·m⁻², which were comparable and consistent with the eukinetic CT. It should be noted that the average SVRI values among the studied groups were statistically insignificant, but the SVRl were greater in Group I than in Group II (30.78 ± 0.76 r.u. versus 28.47 ± 0.69 r.u. (P = 0.029).

A ratio of CTs in swimmers with different sports classes was interesting. Thus, in the group of MS and MSIC swimmers, it was as follows: 50.0 %: 44.4 %: 5.6 % of hypokinetic, eu-, and hyperkinetic type, respectively. That is, there was a tendency to hypokinetic CT (P = 0.744) prevalence compared to eukinetic and hyperkinetic CT (P = 0.872). In the group of first-class and CMS swimmers, the CT ratio was as follows: 38.0 %: 54.0 %: 8.0 % of hypokinetic, eu- and hyperkinetic CT, respectively. That means, there was a tendency to the eukinetic CT prevalence (P = 0.284). It should be noted that in the groups, with raising of the sports class, there were a tendency to increase in the number of swimmers with hypokinetic CT (from 38.0 % to 50.0 %) and decrease in the number of swimmers with hyperkinetic CT (from 8.0 % to 5.6 %).

In the group of MS and MSIC swimmers, the ratio of autonomic tone was 61.1 %: 38.9 %: 0.0 %, and in the group of first-class and CMS swimmers – 68.0 %: 30.0 %: 2.0 %, corresponding to vagotonia, eutonia and sympathicotonia, respectively. Thus, the lower the sports class of swimmers, the greater number of athletes with vagotonia (P = 0.092). It should be noted that according to the data of I. M. Kurbanova [8], in young swimmers, with raising of the sports class from the third-class sportsman to MS, the percentage of normotonics significantly decreases and the proportion of sympathicotonics is nearly tripled.

The relative value of physical working capacity was the greatest in Group I – 18.37 ± 0.37 kgm·min⁻¹·kg⁻¹ in comparison with Group II – 16.30 ± 0.41 kgm·min⁻¹·kg⁻¹ (P = 0.0006).

The FSI was significantly higher in Group I compared to Group II (6.924 ± 0.205 versus 6.061 ± 0.233 r.u., P = 0.009). At the same time, according to our classification, swimmers of both groups matched the level “below average” on this index.

The correlation analysis of the studied indicators in Group I swimmers showed a positive correlation between Mo and SVR (r = 0.630, P = 0.0001), Mo and SRVI (r = 0.615, P = 0.0001), Mo and PWC170/kg (r = 0.442, P = 0.007) and a negative correlation between Mo and HR (r = -0.752, P = 0.0001) and Mo and CI (r = -0.519, P = 0.001). The correlation between Mo and PWC170/kg as well as Mo and CI, is very important, as it shows that the increase in the athlete’s current functional state, manifested by the HR decrease, is followed by high physical working capacity and low CI values which come close to hypokinetic CT.

The similar analysis of the studied indicators in first-class and CMS swimmers showed positive correlation between Mo and SI (r = 0.501, P = 0.0001), Mo and SVR (r = 0.332, P = 0.018), Mo and SVRI (r = 0.401, P = 0.004), Mo and PWC170/kg (r = 0.427, P = 0.002), stress-index and CI (r = 0.385, P = 0.006) and negative correlation between Mo and HR (r = -0.770, P = 0.0001), Mo and CI (r = -0.411, P = 0.003). Swimmers of this classes as well as MS and MSIC athletes had rather strong positive correlation between Mo and PWC170/kg, Mo and CI, in addition, between stress-index and CI, which indicated that the decrease in stress-index was followed by a CI decrease, which could reach the values characteristic for hypokinetic CT.

**Discussion**

In the available scientific literature, we have found some works related to the studies on the swimmers’ HRV, central hemodynamics, and physical working capacity. Thus, according to the results of T. V. Krasnoperova [6] obtained during the examination of 22 swimmers, the average observed HR was 58.17 ± 1.68 bpm. M. A. Kryanova and I. N. Kalinina [7] found that the average HR among 24 sprint swimmers from first-class to MS sportsmen in the pre-competition period was 62.90 ± 2.91 bpm. A. D. Vikulov et al. [2], in the middle of the competitive period among twenty 18–23-year-old swimmers from CMS to MSIC, obtain an average value of HR which accounted for 56.4 ± 5.5 bpm. Our previous study has shown, that the average value of HR in 13 first-class and CMS swimmers in the pre-competition period was 60.1 ± 1.8 bpm, and HR in 12 MS and MSIC swimmers was 55.1 ± 2.5 bpm [11]. Quite close values have been obtained in the present study; first-class and CMS swimmers (n = 50) had HR 60.40 ± 1.35 bpm, while MS and CMS swimmers (n = 36) had HR 56.0 ± 1.76 bpm. Thus, highly qualified swimmers were characterized by the average value of HR within 55.1 ± 2.5 – 62.90 ± 2.91 bpm range. However, not all authors conducted their studies in the pre-competition period, which could have affected the study results.
Conclusions

1. Sprint swimmers from first-class sportsman to Master of Sports of International Class (average age – 18.6 ± 0.3 years, average swimming experience – 10.40 ± 0.44 years) have body height of 186.6 ± 1.23 cm, body weight of 77.2 ± 1.36 kg, HR – 56.0 ± 1.76 bpm, CI – 2.795 ± 0.005 l·min⁻¹·m⁻², PWC₁₇₀kg – 18.37 ± 0.37 kgm·min⁻¹·kg⁻¹, IFS – 6.924 ± 0.205 r.u.

2. Sprint swimmers from Master of Sports to Master of Sports of International Class (average age – 18.61 ± 0.41 years, average swimming experience – 10.40 ± 0.44 years) have body height of 186.6 ± 1.23 cm, body weight of 77.2 ± 1.36 kg, HR – 56.0 ± 1.76 bpm, CI – 2.795 ± 0.005 l·min⁻¹·m⁻², PWC₁₇₀kg – 18.37 ± 0.37 kgm·min⁻¹·kg⁻¹, IFS – 6.924 ± 0.205 r.u.

3. Sprint swimmers from first-class to Candidate Master of Sports (average age – 15.60 ± 0.33 years, average swimming experience – 7.63 ± 0.23 years) have body height of 178.00 ± 0.92 cm, body weight of 65.90 ± 0.98 kg, HR – 60.40 ± 1.35 bpm, CI – 2.925 ± 0.063 l·min⁻¹·m⁻², stress-index – 57.51 ± 7.66 r.u., PWC₁₇₀kg – 16.30 ± 0.41 kgm·min⁻¹·kg⁻¹, IFS – 6.061 ± 0.233 r.u.

4. In swimmers from first-class to Master of Sports of International Class, the positive correlations between Mo and PWC₁₇₀kg, stress-index and CI, and the negative correlation between Mo and CI are the most significant.
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