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Dynamic monitoring of functional status in athletes performing physical loads in vertical and horizontal planes with equivalent energy supply for muscle training

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Abstract

Purpose. To dynamically monitor the functional state of athletes undergoing physical loads in vertical and horizontal planes with similar energy demands during the training cycle.

Material & Methods. A total of 47 athletes were examined, including 27 runners at the 400 m distance and 20 swimmers at the 100 m distance in the preparatory and competition periods of the training process. Heart rate variability and central hemodynamics were measured using the automated diagnostic platform Cardio+. Physical performance was assessed on the Corival Lode cycle ergometer using the submaximal PWC170 test.

Results. During the competitive season, runners exhibited a trend towards increased parasympathetic influence and decreased sympathovagal index. Significant decreases were found in heart rate and cardiac index, with a shift in circulation type from eukinetic to hypokinetic. Analysis of circulation type distribution revealed an increase in hypokinetic circulation and the elimination of hyperkinetic circulation. Physical performance significantly improved, with increases in PWC170/kg and physical fitness index. A negative correlation was observed between performance metrics and cardiac index during the preparatory period. Swimmers showed trends towards increased parasympathetic activity and decreased sympathetic activity, though these changes were not statistically significant. A trend towards decreased cardiac index was observed. Circulation type distribution shifted towards hypokinetic circulation. PWC170/kg and physical fitness index significantly increased. Highly-trained runners demonstrated significant decreases in cardiac index and increases in performance metrics during the competitive period. Negative correlations were found between performance metrics and cardiac index. No significant correlations were observed in lower-level athletes.

Conclusions. During the competitive period, compared to the preparatory period, runners and swimmers exhibited a statistically significant increase in physical performance and an improved physical fitness index. Analysis of heart rate variability parameters, however, revealed no statistically significant differences. Correlation analysis revealed that, in the competition period, a decrease in cardiac index to a physiologically advantageous hypokinetic circulatory profile in runners was associated with increased physical performance, while in swimmers, it was associated with a shift in autonomic nervous system vegetative balance. A beneficial outcome of appropriate sports training is the enhancement of functional capacity within the body's primary systems. This leads to improved athletic performance, as demonstrated by gains observed in runners and swimmers.

Keywords: runners, swimmers, heart rate variability, central hemodynamics, physical performance, training periods in sport, energy provision for training, sports qualification, correlation.

Introduction

As we delve further into our research, we revisit the topic of comparing indicators among athletes, emphasizing the need for a nuanced approach. Such comparisons must account for factors including age, training experience, sports qualification, gender, height (in team sports), and body mass (in combat sports, weightlifting, kettlebell lifting, and certain rowing disciplines). The stage of the training cycle – preparatory versus competitive – is also critical, as is player position in team sports (e.g., striker, goalkeeper). An intriguing aspect of these comparisons focuses on athletes developing similar physiological demands, such as endurance in marathon runners and road cyclists, or speed in sprint runners and swimmers (Mykhalyuk, 2018).

Recent research has increasingly focused on the comparison of functional indicators of athletes with different physiological conditions during training and competition, particularly those performing exercises in the vertical (running) or horizontal (swimming) plane with comparable energy expenditure. For example, a group of scientists investigated respiratory and hemodynamic responses in swimmers and runners, assessing physical performance indicators and central hemodynamics (Holmer et al., 1974). Further studies have compared runners and swimmers using echocardiographic data (Colan et al., 1987; Currie et al., 2018), and Wasfy et al. (2015) compared runners and rowers using standard and speckle-tracking two-dimensional echocardiography, revealing both similarities and differences. Ukrainian studies have also examined chest radiography indicators in qualified swimmers during graded exercise tests in varying body positions (Sinyugina & D'omin, 2014).

It is known that an athlete's functional state changes throughout the sports season under the influence of training loads, with the most pronounced changes occurring during competition, especially at peak form, followed by a return to baseline values during the off-season. This dynamic poses a challenge for sports medicine specialists seeking to track athlete health. However, significant logistical difficulties often hinder longitudinal research. These include athlete motivation, competition schedules, training camps, and reluctance to participate in pre-competition testing, particularly among veteran athletes (MASTERS category) (Graziano et al., 2024) and those in sports with a high risk of injury (e.g., martial arts) (Ghafouri et al., 2020). Despite these challenges, Ljungqvist et al. (2009) and others emphasize the importance of periodic monitoring for injury prevention and health maintenance.

The modern sports calendar, characterized by prolonged competition periods (4–5 months or more), necessitates a flexible approach to training load management, further complicating longitudinal studies. Consequently, research often includes limited numbers of athletes observed throughout the entire preparatory and competition cycle. Our group experienced this limitation, examining approximately 100 throwing event athletes (Mikhalyuk et al., 1988), and smaller cohorts of sprinters (Mykhalyuk et al., 2016b; Mykhalyuk et al., 2016c), 400-meter runners (Mykhalyuk et al., 2016a; Mykhalyuk et al., 2016d), and short-distance swimmers (Mykhaliuk et al., 2021). This limitation is not unique to our research; similar constraints have been reported by colleagues, such as Polish researchers studying 11 volleyball players (Podstawski et al., 2014) and a multinational team observing 15 futsal players (Oliveira et al., 2013) and 9 handball players (Boraczyński, & Urniaż, 2008).

Despite these limitations, gaps remain in our understanding of the functional differences between athletes performing comparable work in vertical and horizontal planes. Conflicting data, a scarcity of longitudinal studies examining heart rate variability, central hemodynamics, and physical performance indicators, and the absence of direct comparisons between 400-meter runners and 100-meter swimmers served as the impetus for this research.

The aim of this study was to longitudinally assess the functional state of athletes undergoing physical loads in vertical and horizontal planes with similar energy demands during the training cycle.

Material and Methods

Participants

The research was conducted after obtaining informed consent from all participants. A total of 27 Ukrainian male runners specializing in the 400-meter distance were studied (qualification ranging from 3rd class athlete to Master of Sports of Ukraine, age ranging from 15 to 28 years, with a mean aged of 18.9±0.72 years). The comparison group consisted of 20 Ukrainian male swimmers specializing in the 100-meter distance (qualification ranging from 1st class athlete to Master of Sports, age ranging from 12 to 24 years, with a mean age of 16.5±0.81 years). All participants were free of known cardiovascular, respiratory, and metabolic diseases. Exclusion criteria included any current illness or use of medications known to affect autonomic function or cardiovascular performance.

Measuring heart rate variability, central hemodynamics, and physical performance

Heart rate variability (HRV) was studied according to the recommendations of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, which allows for the assessment of the influence of the autonomic nervous system (ANS) on the functional state of the sinus node of the heart (Edmonds et al., 2020). HRV was assessed in the supine position using the automated diagnostic platform Cardio+ (Metecol, Ukraine). Time domain (modal R-R interval duration – Mo, s; mode amplitude – AMo, %; variation range – D, s) and calculated HRV parameters were analyzed: the vagal balance index (AMo/D, %/s), autonomic rhythm index (ARI, $1/s^2$), adequacy index of regulatory processes (AIRP, %/s), and stress index, arbitrary units (a.u.). All HRV analyses were performed according to established guidelines ("Heart rate variability: standards…", 1996).

Data on central hemodynamics were obtained using the automated tetra-polar rheography method (Cybulski et al., 2012; Kim et al., 2019) with measurements taken in the supine position. Stroke volume (SV) and cardiac output (CO) were calculated, as well as stroke index (SI) and cardiac index (CI), total peripheral resistance (TPR), and peripheral vascular resistance index (PVRI). Central hemodynamics parameters was assessed using the automated diagnostic platform Cardio+ (Metecol, Ukraine).

To assess physical performance, a widely accepted methodology on a cycle ergometer (Corival Lode, the Netherlands) was used with a submaximal PWC_{170} test (Mykhaliuk et al., 2022), and the relative value of physical performance, i.e., $PWC_{170/kg}$, was calculated.

The physical fitness index (PFI) was calculated using the formula we proposed (Mykhalyuk et al., 2008). Heart rate (HR) and blood pressure (BP) were measured in the subject in a seated position on a cycle ergometer, and the Robinson Index was calculated. Subsequently, HR and BP were measured after a second bout of exercise on the cycle ergometer during a submaximal PWC_{170} test, and again at the 5-minute recovery period. The PFI was calculated using the formula:

$$\mathrm{PFI} = \frac{\mathrm{PWC}_{170/\mathrm{kg}}\,(\mathrm{W/kg})}{\mathrm{RI}_1 + \mathrm{RI}_2 + \mathrm{RI}_3} \times 1000\ (\mathrm{a.u.})$$

$PWC_{170/kg}$ – relative PWC_{170} value (W/kg);

IR_1 – Robinson Index (baseline data);

IR_2 – Robinson Index after the second exercise bout on the cycle ergometer;

IR_3 – Robinson Index at the 5-minute recovery period;

1000 – coefficient for converting results to whole numbers.

A PFI of 12.0 a.u. or more corresponds to a "high" assessment, while values ranging from 10.0 to 11.9 a.u. are considered "above average", 8.0 to 9.9 a.u. are "average", 6.0 to 7.9 a.u. are "below average", and 5.9 a.u. or less are "low".

Statistical analysis

Data were analyzed using StatSoft Statistica software. Descriptive statistics were calculated as means±standard error of the mean (SEM). Data normality was assessed using the Shapiro-Wilk test. Paired samples t-tests were used to compare two subsets of data. Relationships between categorical variables were assessed using Fisher's exact test. A p-value of <0.05 was considered statistically significant.

Results

Runners

In runners during the competitive season, changes in HRV parameters were analyzed (Table 1). The Mo increased from 0.980±0.003 s to 1.030±0.03 s (p>0.05). The D increased from 0.467±0.04 s to 0.512±0.07 s (p>0.05). AMo/D increased from 88.411±11.30 %/s to 104.297±6.24 %/s (p>0.05). The stress index increased from 47.348±6.75 a.u. to 54.075±9.40 a.u. (p>0.05). None of these observed changes were statistically significant.

In the competitive period, runners demon-

Table 1. **HRV parameters in 400 m runners: preparatory and competitive periods, mean±SEM**

Parameter	Preparatory Period	Competitive Period	p-value
Mo, s	0.980±0.003	1.030±0.03	>0.05
D, s	0.467±0.04	0.512±0.07	>0.05
AMo/D, %/s	88.411±11.30	104.297±6.24	>0.05
Stress index, a.u.	47.348±6.75	54.075±9.40	>0.05

strated a significant decrease in HR from 56.5±1.74 to 52.5±1.44 beats per minute (bpm) ($p<0.05$) and CI from 2.913±0.10 to 2.684±0.05 L/min/m² ($p<0.05$). In the preparatory period, CI corresponded to the eukinetic type of circulation (TC), while in the competitive period, it shifted to the hypokinetic type. Individual analysis of the percentage distribution of TC revealed the following in the preparatory period: 25.9% – hypokinetic TC, 59.3% – eukinetic TC, and 14.8% – hyperkinetic TC (Figure 1). Thus, athletes tended towards a predominance of eukinetic TC ($p=0.140$). In the competitive period, the percentage distribution of TC changed to 63.0% – hypokinetic TC, 37.0% – eukinetic TC, and 0% – hyperkinetic TC, indicating a trend towards a predominance of hypokinetic TC ($p=0.191$) and the absence of athletes with hyperkinetic TC. Other central hemodynamic parameters (SI, TPR, PVRI) did not show statistically significant differences.

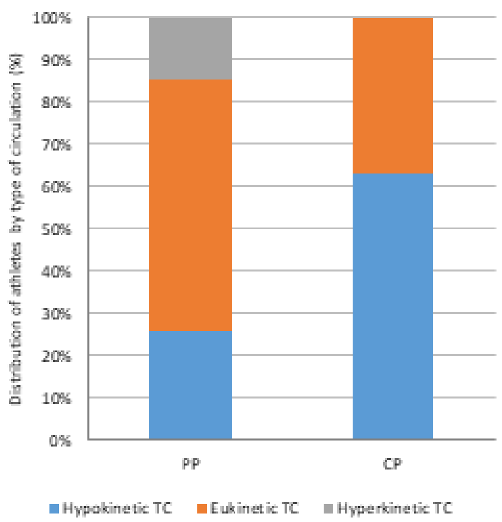

Figure 1. Distribution of circulation types in 400 m runners during preparatory (PP) and competitive (CP) periods.

Significant differences were found in physical performance and PFI measurements (Tale 2). The $PWC_{170/kg}$ value in the preparatory period was 3.362±0.124 W/kg, and in the competitive period, it increased to 3.648±0.111 W/kg (an increase of 8.5%, $p<0.05$). The PFI increased by 17.9%, from 7.991±0.370 to 9.420±0.400 a.u. ($p<0.05$). According to our classification (Mykhalyuk et al., 2008), these values corresponded to a "below average" rating in the first case and an "average" rating in the second. An analysis of individual PFI values in the preparatory period showed the following distribution: 3 athletes (11.11%) had a "low" rating, 11 (40.74%) had a "below average" rating, 6 (22.22%) had an "average" rating, and 7 (25.93%) had an "above average" rating. In the competitive period, significant changes occurred in the athletes' functional state, reflected in the distribution of ratings: 2 (7.41%) athletes had a "low" rating, 5 (18.52%) had a "below average" rating, 10 (37.03%) had an "average" rating, 6 (22.22%) had an "above average" rating, and 4 (14.81%) had a "high" rating. Thus, in the competitive period, the number of runners with an "average" rating increased due to a nearly twofold decrease in the number of athletes with "low" and "below average" ratings, and 4 athletes achieved a "high" rating.

Correlation analysis of the studied parameters revealed a significant negative correlation between $PWC_{170/kg}$ and CI ($r=-0.50$, $p<0.05$), PFI and CI ($r=-0.55$, $p<0.05$), and $PWC_{170/kg}$ and the stress index ($r=-0.36$, $p<0.05$) in the preparatory period. This indicates that the improvement in runners' physical performance is associated with a decrease in cardiac index to values characteristic of the hypokinetic TC and a decrease in the stress index to values indicating a predominance of parasympathetic influences of the ANS. In the competitive period, no significant correlations were found between the studied parameters. However, positive changes in sports performance were observed: one 1st class athlete achieved the Candidate for Master of Sports standard, and two 3rd class athletes improved to the 2nd class sports qualification.

Swimmers

In swimmers, analysis of HRV parameters during the competitive period showed no statistically significant changes compared to preparatory period (Table 3). Observed changes included an increase in the Mo parameter from 0.890±0.035 s to 0.938±0.036 s ($p>0.05$), an increase in the D parameter from 0.523±0.006 s to 0.599±0.119 s ($p>0.05$), a decrease in AMo/D from 105.67±29.21 %/s to 78.16±10.93 %/s ($p>0.05$), and a decrease in the stress index from 60.09±15.72 a.u. to 43.73±6.73 a.u. ($p>0.05$).

Regarding central hemodynamics, there

Table 2. **Runners – physical performance metrics, mean ± SEM**

Metric	Period	Value	Change (%)	p-value
$PWC_{170/kg}$, W/kg	Preparatory	3.362±0.124		
	Competitive	3.648±0.111	+8.5	p<0.05
PFI, a.u.	Preparatory	7.991±0.37		
	Competitive	9.420±0.40	+17.9	p<0.05

Table 3. **HRV parameters in 100 m swimmers: preparatory and competitive periods, mean ± SEM**

Parameter	Preparatory Period	Competitive Period	p-value
Mo, s	0.890±0.035	0.938±0.036	> 0.05
D, s	0.523±0.006	0.599±0.119	> 0.05
AMo/D, %/s	105.67±29.21	78.16±10.93	> 0.05
Stress index, a.u.	60.09±15.72	43.73±6.73	> 0.05

Table 4. **Swimmers – physical performance metrics, mean ± SEM**

Metric	Period	Value	Change (%)	p-value
$PWC_{170/kg}$, W/kg	Preparatory	2.539±0.107		
	Competitive	2.955±0.086	+16.38	p<0.001
PFI, a.u.	Preparatory	5.558±0.322		
	Competitive	6.952±0.272	+25.08	p<0.001

was a tendency towards a decrease in CI from 2.954±0.126 to 2.862±0.088 L/min/m² ($p>0.05$). The obtained values corresponded to the eukinetic TC in both training periods. The percentage distribution of TC in the preparatory period was as follows: 45.0% – hypokinetic, 45.0% – eukinetic, and 10.0% – hyperkinetic (Figure 2). In the competitive period, a change was observed: 55.0% – hypokinetic, 45.0% – eukinetic, and 0% – hyperkinetic. Despite a numerical increase of 2 swimmers (10%) exhibiting the eukinetic TC, we interpret the observed changes in the competitive period as favorable, primarily due to the complete elimination of the hyperkinetic TC, which is physiologically disadvantageous.

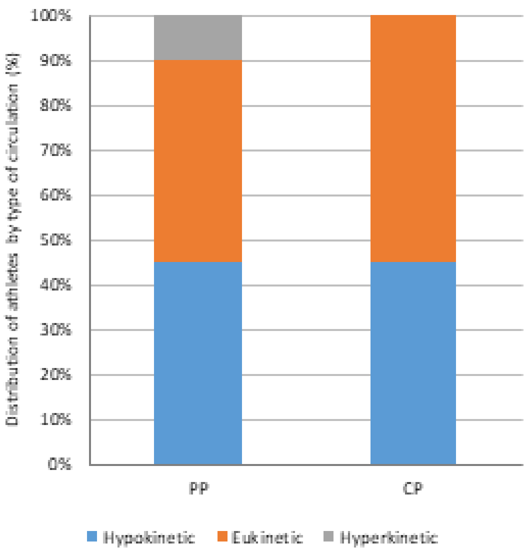

Figure 2. **Distribution of circulation types in 100 m swimmers during preparatory (PP) and competitive (CP) periods.**

Significant changes were observed in the relative value of physical performance and the PFI (Table 4). The average $PWC_{170/kg}$ value in the preparatory period was 2.539±0.107 W/kg, and in the competitive period, it increased by 16.38% to 2.955±0.086 W/kg ($p<0.001$). The PFI significantly increased by 25.08%, from 5.558±0.322 to 6.952±0.272 a.u. ($p<0.001$). Based on our proposed classification, the PFI in the preparatory period corresponded to a "low" rating, and in the competitive period, it increased to "below average".

The individual assessment of PFI in the preparatory period had the following distribution: a "low" rating for 12 swimmers (60.0%), "below average" for 7 (35.0%), and "average" for 1 swimmer (5.0%). In the competitive period, the following changes were observed: a "low" rating for 7 (35.0%), "below average" for 10 (50.0%), and "average" for 3 swimmers (15.0%). Thus, in the competitive period, the number of swimmers with an "average" rating increased by 10.0%, those with a "below average" rating increased by 15.0%, and those with a "low" rating decreased by 25.0%.

The correlation analysis conducted in the preparatory period revealed a significant positive correlation between Mo and $PWC_{170/kg}$ ($r=0.46$, $p<0.05$), ARI and CI ($r=0.50$, $p<0.05$), AIRP and CI ($r=0.53$, $p<0.05$), and stress index and SI ($r=0.52$, $p<0.05$). A negative correlation was also observed between Mo and CI ($r=-0.56$, $p<0.01$). It is known that Mo reflects the level of functioning of the cardiovascular system. Higher Mo values correlate with a greater influence of the parasympathetic branch of the ANS and, in this case, with higher $PWC_{170/kg}$ values. The ARI allows for the assessment of autonomic balance; its decrease indicates a shift towards parasympathetic regulation, potentially affecting CI. A decrease in the AIRP also indicates the predominance of parasympathetic influences and a decrease in CI. A decrease in the stress index contributes to a reduction in SI. Ultimately, a significant increase in Mo correlates with a decrease in CI, which may contribute to its economization when reaching values corresponding to the hypokinetic TC.

In the competitive period, the overall trend of correlational relationships remained. A significant positive correlation was found between Mo and PFI (r=0.53, p<0.05) and between ARI and CI (r=0.51, p<0.05).

It is also worth noting that in the competitive period, four athletes with the Candidate for Master of Sports qualification achieved the Master of Sports standard, two 1st class athletes became Candidates for Master of Sports, and two 2nd class athletes became 1st class athletes. Thus, in the studied group, there were seven Masters of Sports, seven Candidates for Master of Sports, and six 1st class athletes.

High-class athletes

In sports, the training process differs not only by preparation periods but also by sports qualification. While the competitive period for high-level athletes is characterized by preparation and participation in competitions, for lower-level athletes, it involves continuing to perform general physical and technical preparation exercises that were carried out in the preparatory period. To conduct a more detailed analysis of the changes in the studied parameters in the competitive period, we separately identified a group of high-level runners (n=21), including six Masters of Sports, five Candidates for Master of Sports, and ten 1st class athletes, and compared them with swimmers (n=20), comprising seven Masters of Sports, seven Candidates for Master of Sports, and six 1st class athletes.

High-level runners in the competitive period exhibited some reduction in HR from 55.4±2.07 to 51.4±1.59 bpm (p>0.05). Regarding central hemodynamic parameters, there was a significant decrease in CI from 2.835±0.10 to 2.622±0.04 L/min/m² (p<0.05). Thus, while the average CI value in the preparatory period corresponded to the eukinetic type, in the competitive period, it shifted to the hypokinetic type. The percentage distribution of blood flow types in the preparatory period was as follows: 28.6%:61.9%:9.5%, corresponding to hypo-, eu-, and hyperkinetic types, with a tendency towards a predominance of the eukinetic type (p=0.177). In the competitive period, it was 71.4%:28.6%:0%, indicating a trend towards a predominance of the hypokinetic type (p=0.071) and the absence of athletes with the hyperkinetic TC. Among other central hemodynamic parameters (SI, TPR, PVRI), no significant differences were found.

Among the physical performance parameters, there was a significant increase in the $PWC_{170/kg}$ value by 7.95% – from 3.513±0.122 to 3.792±0.112 W/kg (p<0.05). Additionally, there was an increase in the average PFI value by 20.2% – from 8.205±0.43 to 9.865±0.45 a.u. (p<0.05). In both cases, the PFI values corresponded to an "average" rating. However, an individual analysis revealed that in the preparatory period, 4 athletes (19.1%) had a "low" rating, 7 (33.3%) had a "below average" rating, 3 (14.3%) had an "average" rating, and 7 (33.3%) had an "above average" rating. In the competitive period, significant changes were observed. There were no athletes with a "low" rating, 4 (19.0%) had a "below average" rating, 7 (33.3%) had an "average" rating, 6 (28.7%) had an "above average" rating, and 4 (19.0%) had a "high" rating. Thus, in the competitive period, the number of high-level athletes with an "average" rating increased due to the absence of athletes with a "low" rating and a decrease in those with a "below average" rating. Furthermore, 4 runners achieved a "high" rating.

The results of the correlation analysis conducted between the integral indicators of HRV, central hemodynamics, and physical performance demonstrated a negative association between $PWC_{170/kg}$ and CI, r=−0.46 (p<0.05), and between PFI and CI, r=−0.56 (p<0.05) in high-level athletes during the preparatory period. In the competitive period, the number of correlations increased due to the negative relationship between physical performance, PFI, and stress index, namely: $PWC_{170/kg}$ and CI, r=−0.36 (p<0.05), PFI and CI, r=−0.39 (p<0.05), $PWC_{170/kg}$ and stress index, r=−0.76 (p<0.05), and PFI and stress index, r=−0.71 (p<0.05). Thus, we have established a relationship between the studied integral indicators, indicating that the increase in physical performance and PFI in highly qualified athletes during the competitive period is associated with a decrease in CI to physiologically advantageous hypokinetic values and a decrease in the stress index to values indicating a predominance of parasympathetic influences of the ANS.

It should be noted that a similar correlation analysis conducted among 3rd and 2nd class athletes did not reveal any significant correlations in either period of the training process.

Discussion

Comparison of the state of various human body systems in vertical versus horizontal postures has always been of scientific interest. It is well-known that athletic activity during swimming exhibits certain physiological peculiarities that distinguish it from physical work performed in the usual air environment. These characteristics are determined by mechanical factors associated with movement in a dense aquatic environment and by the horizontal body posture, which creates favorable conditions for enhanced venous return and increased cardiac filling during diastole. Conversely, in a vertical posture on land, hydrostatic pressure from the blood column elevates pressure in the working leg vessels. Consequently, while the horizontal posture during swimming facilitates venous return and cardiac filling, the vertical posture on land presents the challenge of elevated hydrostatic pressure in the lower body vessels that must be overcome for effective circulation.

A study by Poliner et al. (1980), which compared left ventricular performance in healthy subjects at rest and during physical exercise in the supine and upright positions, reported that at rest, left ventricular end-diastolic volume in the supine position was significantly higher than in the upright position ($p<0.02$), suggesting a higher stroke volume in the supine position at rest. This can be explained by higher venous return in the horizontal position along with the Frank-Starling mechanism.

Holmer et al. (1974) compared submaximal and maximal exercise in swimming and running among 5 men aged 18-29 years. The results revealed similar values for cardiac output, stroke volume, and HR. However, maximum oxygen uptake (VO_{2max}) and cardiac output in swimming were 15% and 10% lower, respectively, while the maximum stroke volume of the heart did not significantly differ from running.

Echocardiographic studies conducted among 11 swimmers and 11 long-distance runners revealed an increased left ventricular (LV) mass compared to the control group. Runners showed LV dilatation with increased wall thickness. Peak systolic wall stress and time-integral of wall stress, as well as myocardial oxygen consumption, were within normal limits for both runners and swimmers. However, the end-systolic wall stress was low in swimmers and normal in runners (Colan et al., 1984).

In the study by Currie et al. (2018) sixteen elite swimmers (mean age 23±2 years, 81% male, 69% white) and sixteen elite runners, matched for age, sex, and race, participated. Swimmers competed in 50-200 m and 400-1500 m events, while the runner group included sprinters (100-400 m), high jumpers, and long-distance runners (≥800 m). Eleven swimmers swam freestyle, 3 swam breaststroke, and 2 swam backstroke. Through echocardiographic investigation, the authors demonstrated that runners, compared to swimmers, had a higher cardiac output due to a higher HR (56 vs. 49 bpm, $p<0.001$), while all other indices of left ventricular systolic function and dimensions were similar between groups. Thus, activities such as swimming and running appear to have a similar impact on left ventricular structure or systolic function, as these parameters were comparable between groups, further supporting the concept of no left ventricular function differences specific to these sports. The authors suggest that running is associated with faster left ventricular untwisting during diastole and enhanced early diastolic filling, and further research is needed to determine whether these observations are a product of the predominant exercise stimulus or a necessary adaptation to facilitate filling during vertical exercise.

A comparison of echocardiography in 40 male long-distance runners and 40 rowers, without reporting the age or athletic qualification of the participants, revealed an enlarged volume and increased left ventricular mass in rowers, while the left ventricular mass in runners was within normal limits. Right ventricular dilatation and left ventricular systolic function were similar in both groups. The authors conclude that cardiac adaptation significantly differs depending on the athletes' specialization, despite similar physical qualities (endurance). They emphasize the need for further investigation into the mechanisms of this differentiated adaptation and the development of definitive normative values for specific sports (Wasfy et al., 2015).

For understandable reasons, the presented literature review complicates drawing clear conclusions about the impact of physical exercise on runners and swimmers. Many studies included comparison groups of athletes who differed significantly in various parameters, particularly age and athletic level. Some studies did not consider the distance covered by the athletes, and one runner group comprised sprinters, high jumpers, and middle-distance runners. Similarly, the swimmer group included sprinters, middle-distance, and long-distance swimmers.

Despite the limitations of the conducted studies, it remains a fact that the structural and functional parameters of the heart in runners and swimmers are comparable. It can also be assumed that the differences will likely be smaller when the comparison groups are more homogeneous. These requirements were taken into account in our comparison of athletes performing physical exercises in vertical and horizontal body positions, ensuring they were of the same age, gender, sports qualification, competitive distance completion time, and muscle energy supply.

Unfortunately, there is a lack of studies in the medical literature on the dynamic observations of athletes' functional state. We have conducted research analyzing cerebral and central hemodynamic indicators in the annual cycle of the training process among track and field athletes, including 31 women and 67 men (Mikhalyuk et al., 1988). We also managed to examine slightly smaller groups of sprinters (men – 35, women – 15) in the dynamics of the annual training cycle (Mikhalyuk et al., 2016b; Mikhalyuk et al., 2016c), runners on the 400-meter distance (men – 27, women – 22) (Mikhalyuk et al., 2016a; Mikhalyuk et al., 2016d), and 20 male swimmers (Mikhalyuk et al., 2021). Our foreign colleagues also face a similar challenge in recruiting a large number of athletes for dynamic observations.

A study of HRV in 11 volleyball players, conducted during pre-competition and competition periods, revealed differences in spectral and temporal HRV parameters. A significant increase in the VLF (%) indicator during the competition period may be due to increased psychophysiological arousal. The authors believe that the detected resting bradycardia, according to the analysis of temporal HRV indicators, may result from changes in the sinoatrial node, reflecting the impact of prolonged training on the heart's conduction system. The high level of physical activity of volleyball players during the studied periods likely contributes to a decrease in vagal tone and a shift in the balance of the ANS towards the sympathetic system, which may be a consequence of overtraining (Podstawski et al., 2014).

An international study conducted by researchers from Brazil, Australia, and Spain combined the results of observations of 15 futsal players. They found significant improvements in some HRV indices during the competition period compared to the preparatory period, indicating a prevalence of parasympathetic regulation (Oliveira et al., 2013). The authors believe that monitoring HRV indicators can contribute to determining an athlete's individual adaptation level and early detection of maladaptation signs. According to Kamandulis et al. (2020), dynamic HRV studies were conducted several times a day for 11 weeks, including post-training, among national-level swimmers (n=22, age 14.3±1.0 years). The authors demonstrated that daily HRV did not significantly correlate with training volume or sleep duration. Collectively, these results suggest the limited value of HRV fluctuations in assessing the balance between a young athlete's physical load and its tolerance in daily training practice. However, in the case of a sudden increase or continuation of training load, lower HRV may be a prognostic sign.

Studies conducted by Edmonds et al. (2020) during a 15-week training cycle in female rowers revealed a decrease in parasympathetic modulation of cardiac activity during the competition period. However, no significant correlation was found between training load and HRV data. Factors unrelated to the training process may likely exacerbate the reduction in HRV, emphasizing the need for continued monitoring of external stress sources (e.g., education) among adolescent athletes.

Dynamic observations of 9 Polish handball players at the end of the competition period and the beginning of the preparatory period, preceded by a 4-week general endurance development phase of the next sports season, showed a significant increase in $PWC_{170/kg}$ from 2.73±0.51 to 3.06±0.42 W/kg, $p<0.01$ (Boraczyński, 2008). This indicator reflects the physical performance of athletes.

Over two years, researchers from Spain studied swimmers (12 girls and 14 boys) during the competition period. The research was conducted according to a specific scheme: 21 days before the start, two days before the competition, and two consecutive days after the first and second competitions. The results showed that boys exhibited higher parasympathetic reactivity after the Wingate test during the competition period compared to girls. Girls demonstrated lower autonomic modulation of the heart when comparing the results of the Wingate test obtained before and after two consecutive competition periods (Castillo-Aguilar et al., 2021).

Stanley et al. (2015) suggested using the ln rMSSD : RR ratio (natural logarithm of the square root of mean squared differences of successive R-R intervals [ln rMSSD] and the ratio of ln rMSSD to R-R interval length) to determine vagal saturation, as it normalizes vagal modulations by considering RR intervals, thereby linking vagal and sympathetic modulations. According to Rabbani et al. (2018), a decrease in this ratio indicates parasympathetic saturation, and a simultaneous reduction in ln rMSSD and ln rMSSD : RR during the last week before competitions may suggest optimal athlete readiness. However, Wang et al. (2018) found no association between training load/intensity and HRV, suggesting this combination of indicators should not be relied upon to monitor autonomic heart activity in athletes.

According to Boraczyński & Urniaż (2008), handball players' physical performance indicators were significantly higher during the competition period compared to the preparatory period. We also obtained higher physical performance indicators for both runners and swimmers during the competition period compared to the preparatory period.

Analysis of scientific studies investigating changes in indicators characterizing the functional state of athletes during the transition from the preparatory to the competitive period of training revealed the following. Regarding changes in HRV, there are studies where authors report a prevalence of parasympathetic regulation in soccer players during the competitive period (Rabbani et al., 2018). Similar findings were obtained in our research among 400-meter runners and 100-meter swimmers of both sexes. However, there are also studies indicating a decrease in vagal tone and a reduction in the balance of the ANS towards sympathetic dominance in athletes during the competitive period (Edmonds et al., 2020; Podstawski et al., 2014). Furthermore, in the study by Kamandulis et al. (2020), lower HRV values were recorded in swimmers when the training load was abruptly increased.

Analysis of dynamic studies among sprinters, 400-meter runners, and sprint swimmers revealed that in elite athletes (Master of Sports and Master of Sports of International Class levels) during the competitive period, compared to the preparatory period, there is often an increase in parasympathetic influences of the ANS. A tendency towards a hypokinetic circulation type was also identified, while no athletes with a hyperkinetic circulation type were found. Additionally, there was a statistically significant increase in physical performance and improvement in sports results (Mykhalyuk et al., 2015a; Mykhalyuk et al., 2015b; Mykhalyuk et al., 2015c; Mykhalyuk et al., 2015d; Mykhalyuk et al., 2021).

We believe that HRV is a sensitive technique that clearly responds to an athlete's fatigue. Therefore, the timing of studies relative to competitions is crucial. On the eve of a competition, athletes typically reduce physical loads to recover, which is manifested not by an increase, but rather by a predominance of parasympathetic influences of the ANS. The same applies to the statistically significant observation of the hypokinetic circulation type, which is physiologically advantageous. Regarding physical performance, despite the fact that the training work was not exclusively aimed at developing endurance, athletes experienced a significant increase in it, as both groups required the development of speed endurance; hence the term "long sprint" for the 400-meter run. Thus, most international and Ukrainian studies focus on examining changes in athletes' functional state throughout the training season.

In our previous work, indicators of different sports were compared, and the athletes were not differentiated by gender, qualification, or competitive performance time. The study included 400-meter runners and 100-meter swimmers, whose competitive times were similar. The group of runners consisted of athletes with qualifications ranging from the 3rd class to Master of Sports of International Class, with race times ranging from 67.0 seconds to 51.35 seconds. Among the 100-meter swimmers, with qualifications from the 2nd class to Master of Sports, the time to cover the distance, depending on the swimming style (freestyle – 95.0-75.0 seconds, breaststroke – 75.0-60.0 seconds), was quite close, especially considering the energy supply of muscle training work. It should be noted that the training process for runners and swimmers consisted of cyclic work with an anaerobic-glycolytic orientation, focused on maximum power and the development of speed and strength qualities (Mykhaliuk et al., 2022).

In our study, in addition to comparing changes in indicators related to athletes' functional state during different periods, we provided a rationale for comparisons from the perspective of the performed training and competitive maximum cyclic work aimed at developing speed and strength qualities. As mentioned earlier, the primary criterion that unites these athletes is the energy supply for their muscle training work. In runners with qualifications from the 2nd class to Master of Sports, this ranges from 56.0 to 47.5 seconds, while in swimmers with qualifications from the 2nd class to Master of Sports, depending on the swimming style (freestyle – 84.0-68.5 seconds, breaststroke – 66.5-53.5 seconds), the energy supply relies on lactic anaerobic sources, which last from 30 seconds to 5-6 minutes, during which glycolysis occurs with lactate formation.

The data we obtained from swimmers during the competition period also demonstrates positive dynamics in terms of physical performance, and, most importantly, in sports results, with individual athletes achieving the standards of Master of Sports of Ukraine, Candidate for Master of Sports, and 1st class athlete. Thus, our proposed arguments justifying the validity of comparisons of functional state indicators in athletes performing physical exercises in vertical and horizontal body planes, but of the same gender and sports qualification, developing similar physical qualities, and with muscle training energy supply occurring over a similar period, indicate not only scientific interest but also the interest of coaches from various sports disciplines, who can adopt this methodological approach to the training process. This approach may contribute to optimizing training programs and enhancing athletic performance.

Conclusions

During the competitive period, compared to the preparatory period, runners and swimmers exhibited a statistically significant increase in physical performance and an improved physical fitness index. Analysis of heart rate variability parameters, however, revealed no statistically significant differences. Correlation analysis revealed that, in the competition period, the decrease in cardiac index to a physiologically advantageous hypokinetic circulatory profile in runners was associated with increased physical performance, while in swimmers, it was associated with a shift in autonomic nervous system vegetative balance. A beneficial outcome of appropriate sports training is the enhancement of functional capacity within the body's primary systems. This leads to improved athletic performance, as demonstrated by gains observed in runners and swimmers.

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