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Stimulating Aerobic Energy Supply Reactions of Athletes in Rugby Union

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Abstract

Objectives. The study purpose was to evaluate the effectiveness of an experimental program of training means aimed at stimulating reactions of aerobic energy supply of athletes who are part of Ukraine national rugby union team.

Material and methods. The athletes of the Ukrainian national rugby union team were divided into two homogeneous groups (experimental and control) consisting of 15 individuals. The experimental group underwent a specialized program aimed at developing aerobic energy supply, whereas the control group followed a standard training program. The object of study focused on the training process of Ukraine national rugby union team.

Results. The results of testing rugby players in the experimental group demonstrated reliable changes in reactions of aerobic energy supply under the influence of a program of special training sessions. The most significant alterations were noted in the indicators of kinetics and stability of reactions. The indicators of O_2 consumption and pulmonary ventilation in the intensity zone of anaerobic metabolism threshold increased significantly. There was a tendency to increase indicators characterizing the power of the respiratory response (max V_E), in particular under conditions of growing fatigue (% excess V_E). However, there were no significant changes in indicators of aerobic capacities' components in the athletes' control group.

Conclusions. We believe that the mentioned indicators mostly reflect specialized manifestations of rugby players' aerobic capacities and impact the increase of athletes' special functional capabilities. This has been confirmed by the results of the analysis of urgent adaptive responses registered in model conditions of competition activity. As a result of the implementation of the specified experimental programme during the preparation process, the Ukrainian national team achieved 2nd place at the European Rugby Union Championship in the Trophy division of the 2022-2023 season.

Keywords: rugby, aerobic energy supply, cardiorespiratory system, experimental training program.

Introduction

To stimulate the reactions of aerobic energy supply, types of work in which the activity of the cardiorespiratory system is predominantly activated have been selected (Anderson & Drust, 2023; Miller et al., 2023). The pedagogical component of special training aimed at implementation of physiological stimuli of reactions involves definition of universal criteria for normalization of the load and assessment of its effectiveness. Universal criteria for normalization of the load may include the conditions for the development of cardiorespiratory system and the associated heart rate modes, reflecting the degree of activation (implementation) of a certain physiological stimulus or their complex use (Hulin et al., 2019; McHugh et al., 2019).

Heart rate criteria for control of response stimuli were applied when assessing the effectiveness of special motor activity. To develop the function of aerobic energy supply, operating modes in which the cardiorespiratory system is stimulated and exercises were selected with consideration to key factors of effective adaptation of rugby union athletes were systematized. The results of studies of the components of aerobic energy supply for athletes indicate that the key factors in the reduced aerobic potential of rugby players are expressed via an increase in the efficiency of the neurogenic mechanism. This factor includes an increase in the mobility of the nervous system as an activator of functional reactions of the body and resistance of the central nervous system to increasing fatigue (Grainger et al., 2022; Ahsan & Ali, 2023).

In this case, it is most advisable to use training tools aimed at implementation of a neurogenic stimulus and activation of a neurogenic stimulus under conditions of increasing fatigue. Activation of the respiratory response as a mechanism of respiratory compensation of metabolic acidosis. The analysis showed that to enhance the reaction of respiratory compensation of metabolic acidosis, modes of activation of an "acute" hypoxic stimulus are used in response to physical activity. Increasing the level of aerobic energy supply with no significant acidemic changes in the body (Périard et al., 2023). In this case, we are talking about activating the work of cardiorespiratory system due to the complex activation of neurogenic and acidemic stimulus reactions.

It should be noted that the use of conditions for the implementation of reaction stimuli in the process of functional training in rugby differs with the use of this approach in other sports (Briskin et al., 2016; Prystupa & Tyshchenko, 2017). These differences lie in the use of physical activity modes in which the level of glycolytic energy supply does not reach maximum levels at which the development of aerobic function stops. The work lasts for 5-12 minutes, within the period of predominant implementation of aerobic energy supply.

The criterion for this ability is the stability of the body's cardiorespiratory system. Consistent manifestations of the cardiorespiratory system can be assessed by the dynamics of the heart rate response. This universal criterion is accepted in sports practice as a way to assess changes in aerobic function during work.

The practical significance of this problem has become a prerequisite for conducting this study.

The purpose of the study is to check effectiveness of the experimental program of training means aimed at stimulating reactions of aerobic energy supply of athletes who are part of Ukraine national rugby union team.

Materials and Methods

Participants

The athletes of the Ukraine national rugby union team were divided into two homogeneous groups consisting of 15 people. One of them was experimental, the other was control. The experimental group completed an experimental program aimed at development of aerobic energy supply in one month, and the control group completed a regular training program. Prior to the testing, the procedures were explained to all of them, including possible risks involvement, and after the explanation, an informed consent form was signed. The experiment has been done after every participant was tested. The athletes were free from any injuries or neuromuscular disorder.

The study has been approved by the Institutional Ethics Committee, complied with all the relevant national regulations and institutional policies, followed the tenets of the declaration of Helsinki, and it has been approved by the authors' institutional review committee.

Methods and Procedures

The object of study is the implementation and effects of a training program designed to enhance aerobic energy supply reactions in National Rugby union athletes. This program aims to improve athletes' aerobic performance by focusing on the kinetics and stability of aerobic energy supply under conditions of increased fatigue and near the anaerobic threshold, with the ultimate goal of optimizing athletes' overall performance in competitive rugby union scenarios.

Changes in the reaction of the cardiorespiratory system of rugby players in the experimental group were registered as a result of assessing changes in power, stability and kinetics of the heart rate response. This reaction is an integral indicator of the changes in the cardiorespiratory system under the influence of training means. In addition, changes in this reaction are the most accessible and informative means of assessing changes in the aerobic function of the body when modeling competition activity in many sports (Hendricks et al., 2014; Meron & Saint-Phard, 2017; Lisenchuk et al., 2019), including rugby (Tyshchenko et al., 2018). To assess changes in reaction of rugby players in the experimental and control groups, the analysis of heart rate dynamics was carried out in the process of modeling the competition activity of rugby players. The rate of development of heart rate reaction was assessed under standard load conditions on a running ergometer for 6 minutes. The inclination angle of the treadmill was 0°, while the speed was 0.8 m/s^{-1}.

To standardize the measurements, the criteria of average heart rate were used, which corresponded to the level of maximum oxygen consumption (MOC) and the threshold of anaerobic metabolism (Barnes et al., 2021; Canda et al., 2023). For this purpose, changes in heart rate reactions were analyzed in regards to the intensity of work that took place in the zone of body's aerobic function maximization.

The ability of athletes to repeatedly achieve the reaction values of the cardiorespiratory system in the intensity zone close to the MOC was assessed. At the same time, the ability to repeatedly maintain stability of the reaction peak magnitude and the level of reaction in the intensity zone close to anaerobic metabolism threshold was assessed under the conditions of one match.

As a result of a contrastive analysis of the initial and final testing, differences in the reaction of the initial part of the experiment were obtained; the athletes noted an unstable heart rate at standard competition load. Rugby players achieved peak levels of cardiorespiratory response within a single match. However, the stability of this function has not been documented.

A tendency towards the function stability was noted only when reaching reaction intensity level at the level of anaerobic

Table 1. Orientation of the training process, reaction stimuli, characteristics of the load and conditions for the implementation of neurogenic, "acute" hypoxic and complex neurogenic and acidemic reaction stimuli (generalized data)

Targeted aerobic training	Reaction stimuli	Load conditions	Efficiency criteria
Increase of the efficiency of the neurogenic mechanism at the beginning of work	Neurogenic stimulus	Repeated, 5-second pace acceleration	Reaching peak heart rate response
Increase of the efficiency of the neurogenic mechanism in the process of growing fatigue	Neurogenic stimulus under conditions of growing fatigue	Increase of the pace for every 3 minutes of steady performance	Maintaining a steady heart rate response (sustainability of growth and stability during the period of uniform performance)
Activization of the respirator reaction as a mechanism of respiratory compensation of metabolic acidosis	"Acute" hypoxis stimulus	Linear 30-second increase and linear 30-second decrease in the work intensity for 60 seconds	Reaching and maintaining peak heart rate
Increase of the level of aerobic energy supply with no significant acidemic changes in the body	Neurogenic and acidemic stimulus (complex conditions of use)	–	–

metabolism threshold. Final testing of the rugby players from the experimental group showed significant changes in the reaction of the cardiorespiratory system in response to the experimental training program. The number of reaction peaks in different matches has increased. Stability of the peak values of the heart rate reaction during competition activity was noted. A linear nature of the increase in heart rate response should also be noted, which confirms the dominant influence of the work ensuring aerobic function.

At the same time, it is important to note the need to maintain levels of anaerobic glycolytic energy supply that do not affect inhibition of the nervous system and aerobic energy function of the body. The focus of special means of rugby players training, reaction stimuli and load characteristics in the process of implementing reaction stimuli are presented in Table 1.

The table presents generalized data for the application of conditions for the implementation of reaction stimuli in sports practice to ensure the work of target settings close to the tasks of aerobic training in rugby. The authors' work (Colosio et al., 2018; Pramkratok et al., 2022; Scott et al., 2022) provided the methodological and theoretical basis for our study.

The training program was based on modes of motor activity, which were aimed at sequential stimulation of neurogenic, "acute" hypoxic and acidemic stimulus reactions and on the use of the principle of sequential increase in load. The training program aimed at development of the aerobic energy supply function was carried out for one month (4 weeks). The program was based on motor activity modes aimed at sequential stimulation of neurogenic, "acute" hypoxic and acidemic reaction stimuli.

The principle of sequential increase in load was used. For this purpose, at the first stage of the program (1 week), during each session, athletes of the experimental group completed an amount of work that corresponded to body's optimal response to the load. The body's optimal response to load is associated with achieving and maintaining peak heart rate reaction values in response to an increase in work intensity, of intense training is associated with improved endurance performance (Hurley et al., 1984; Buchheit et al., 2009). The sessions were held in the morning, 1.5-2.0 hours before the main training. Functional training tools and performance efficiency criteria at the first stage are presented below.

The program for the first week of aerobic training of qualified rugby players from the experimental group. The purpose of this research stage was preliminary activation of the cardiorespiratory system.

Days 1, 2, 3 of the first week – application of neurogenic stimulation of the cardiorespiratory system:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes. Two times with a 3-minute rest interval. Part 2 – variable running: a combination of work at the level of 40-50% of the maximum intensity level with short-term 5-second accelerations in 1 minute. Duration of work is 6-8 minutes. The duration of work and the number of accelerations are dosed depending on the degree of increase in heart rate, achievement and maintenance of the peak reaction.

Days 4, 5, 6 of the first week – application of "acute" hypoxic stimulation of the cardiorespiratory system:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes. Two times with a 3-minute rest interval. Part 2 – variable running: a combination of work at 40-50% of the maximum intensity level in combination with 15-second linear increase and linear decrease in the intensity of work every minute. Duration of work is 9-12 minutes. The duration of work and the number of accelerations are dosed depending on the degree of increase in heart rate, achievement and maintenance of the peak reaction.

At the first stage, sessions aimed at activation of acidemic stimulation of aerobic functions were not held.

Day 7 – rest. A long, one-hour walk in fresh air is recommended.

At the second stage (second week) of aerobic training of qualified rugby players from the experimental group, the volume of exercises required during the session was increased. This stimulated an increase in fatigue and the formation of an adequate reaction of the body. This could be observed by changes in heart rate dynamics during standard work.

Standard work was performed at an average heart rate level recorded for 3-5 minutes of steady work at the first stage. During the first and second days of sessions, work intensity was adjusted to optimize the load, at which a tendency to maintain the stability of the heart rate response during work was noted.

This is an important tool for activation of aerobic function and a criterion for assessment of work efficiency during the period of development of predominantly aerobic energy supply, provided that the body's glycolytic reactions are minimized (Weston & Gabbett, 2001).

The sessions were held before noon, taking into account the achieved effect of fatigue and the need to activate recovery processes; the chief training sessions were held in the afternoon in 3.5-4.0 hours. Functional training tools and performance criteria for the first stage are presented below.

The program for the second week of aerobic training of qualified rugby players from the experimental group. The purpose of this research stage was targeted stimulation of the cardiorespiratory system.

Days 1, 2, 3 of the second week – application of neurogenic stimulation of the cardiorespiratory system.

Days 4, 5, 6 – application of "acute" hypoxic stimulation of the cardiorespiratory system:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes. Two times with a 3-minute rest interval. A correction was made to the work intensity in order to standardize the load at a steady heart rate level (±3 beats/min^{-1}) for 1.5-2.0 minutes of work. Part 2 – variable running: a combination of work at a level of 40-50% of the maximum intensity level in combination with 15-second linear increase and 15-second linear decrease in the intensity of work in 1 minute. Series duration is 5 minutes. Number of series is 4.

At the second stage, sessions aimed at activating acidemic stimulation of aerobic functions were also not held.

Day 7 – rest. A long, one-hour walk in fresh air is recommended.

At the third stage (third week) of the aerobic training program for rugby players, long-term modes of steady work were additionally applied, in which stimulation of aerobic energy supply took place under conditions of increasing fatigue. Training sessions were held with focus on activation of acidemic stimulation of the cardiorespiratory system of rugby players.

The efficiency of stimulation of cardiorespiratory function as a result of the use of sequential implementation of neurogenic and acidemic stimulation of reactions is presented in scientific literature (Guo Pengcheng et al., 2020; Efremenko, 2010). The effect of increasing reactivity of the cardiorespiratory system on the next day, 20-24 hours after work, has been shown. Sessions were held from 10 to 11 o'clock in the morning. Taking into account the depth of impact of the load on the body, chief training sessions were held in the afternoon in 5.5-6.0 hours. Functional training tools and performance criteria for the first stage are presented below.

The program for the third week of aerobic training of qualified rugby players from the experimental group. The purpose of this research stage was stimulation of the cardiorespiratory system through the use of conditions for the implementation of neurogenic, "acute" hypoxic and acidemic reaction stimuli.

Days 1 and 2 of the third week – application of neurogenic stimulation of the cardiorespiratory system:

Part 1 – steady running for 5 minutes. Two times with a 3-minute rest interval. A correction was made to the work intensity in order to standardize the load at a steady heart rate level (±3 beats/min^{-1}) for 1.5-2.0 minutes of work. Part 2 – variable running: a combination of work at the level of 40-50% of the maximum intensity level with short-term 5-second accelerations in 30 seconds. Series duration is 3 minutes. Number of series is 5.

Day 3 – neurogenic stimulation of the cardiorespiratory system under conditions of increasing fatigue

Part 1 – steady running for 5 minutes (warm-up). The intensity is 40-50% of the maximum level, selected individually. Part 2 – running at variable intensity for 12 minutes. 5-second maximum accelerations were done every 45 seconds of work.

Day 4, 5 – the use of "acute" hypoxic stimulation of the cardiorespiratory system:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes (warm-up). Part 2 – variable running: a combination of work at a level of 40-50% of the maximum intensity level in combination with 30-second linear increase and 30-second linear decrease in the intensity of work every 3 minutes of work. At the final stage (5-10 s) of 30-second linear increase in load, the intensity of work was maximum. Work time was 12 min.

Day 6 – the use of complex neurogenic and acidemic stimulation:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes. In three minutes, variable work (running) was done: a combination of work at a level of 40-50% of the maximum intensity level with short-term 5-second accelerations in 30 seconds. Series duration is 5 minutes. Number of series is 2. Part 2 – steady running at the peak heart rate level (for 3-6 minutes of work), which was achieved as a result of performing accelerations in the first part of the session. Work time was 12 min.

Day 7 – rest. A long, one-hour walk in fresh air is recommended.

The fourth stage of the program. The fourth stage of the program lasted 12 days. These days included 9 days of experimental training sessions and 3 days to monitor changes in the athletes' performance. In this part of the aerobic training program for rugby players, additional blocks of training sessions were used, the duration of each block was 3 days. The goal of the stage was to achieve the maximum effect of increasing the aerobic function of the body due to the cumulative effect of using unidirectional means of performance stimulating for 3 days, and the cumulative effect of the training cycle. Sessions were held from 10 am to 12 pm.

The amount of special work of rugby players was reduced. Specific elements of rugby players training were worked out. Functional training tools and performance criteria for the first stage are presented below.

Days 1 and 2 (first block) – increase of the function of aerobic energy supply through the implementation of neurogenic stimulation of the cardiorespiratory system.

Part 1 – steady running for 5 minutes. Two times with a 3-minute rest interval. A correction was made to the work intensity in order to standardize the load at a steady heart rate level (±3 beats/min^{-1}) for 1.5-2.0 minutes of work. Part 2 – variable running: a combination of work at the level of 40-50% of the maximum intensity level with short-term 5-second accelerations in 30 seconds. Series duration was 5 minutes. Number of series was 4.

Day 3 (first block)

Part 1 – steady running for 5 minutes (warm-up). The intensity was 40-50% of the maximum level, selected individually. Part 2 – running at variable intensity for 12 minutes. Maximum acceleration for 5 seconds was done every 45 seconds of work.

Day 4 – special work.

Days 5, 6, 7 (second block) – use of “acute” hypoxic stimulation of the cardiorespiratory system:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes (warm-up). Part 2 – variable running: a combination of work at a level of 40-50% of the maximum intensity level in combination with 30-second linear increase and 30-second decrease in the intensity of work every 3 minutes. In the final stage (5-10 s), 30-second linear increase in load; the intensity of work was maximum. Duration – 12 min.

Day 8 – special work.

Days 9, 10, 11 (third block) – complex use of neurogenic, “acute” hypoxic and acidemic stimulation of the cardiorespiratory system:

Part 1 – steady running for 5 minutes. Two times with a 3-minute rest interval. A correction was made to the work intensity in order to standardize the load at a steady heart rate level (±3 beats/min^{-1}) for 1.5-2.0 minutes of work. Part 2 – variable running: a combination of work at the level of 40-50% of the maximum intensity level with short-term 5-second accelerations in 30 seconds. Series duration was 5 minutes. Number of series was 4.

Day 12 – control measurements.

Statistical Analysis

In order to bring the empirical data obtained during the empirical research to a form more suitable for meaningful analysis, a computer type of processing of the obtained empirical information was chosen. All statistical analyses were performed using SPSS Version 22.0 (IBM Corporation). The mean value (X) and standard deviation (s) of indicators of qualified rugby players were measured. The t-test was also used to compare indicators between the control group and experimental group (independent samples) and between groups before and after the experiment (paired samples). A significance level of 0.05 was used for the analyses. Before applying the t-test, a normality check of the data distribution was conducted.

Results

The results of the research made it possible to identify significant changes in the components of the aerobic energy supply of rugby players of Ukraine national rugby union team. In this context, the following key aspects and patterns regarding the influence of a specialized training program on the aerobic capacities of athletes can be identified.

The results of the analysis of changes in the rate of development of the cardiorespiratory system response are presented in Tables 2-4. As a result of the experiment, data have been obtained that made it possible to evaluate changes in the reactions of aerobic energy supply of rugby players. Changes in power, reactions stability kinetics, changes in the reaction of aerobic energy supply in the zone of anaerobic metabolism threshold were analyzed.

The experimental group demonstrated significant improvements in indicators characterizing aerobic capacity, namely maximum oxygen consumption (VO_2max), maximum lung ventilation (max V_E), percentage of excess ventilation (% excess V_E), time to reach 50% of max V_E ($T_{50}V_E$), time to reach a VO_2 plateau, indicating increased levels of aerobic function and oxygen use efficiency during intense exercise.

Thus, the experimental group showed a statistically significant increase in VO_2max by 5.2%, which indicates an improvement in aerobic power and endurance, which is critical for rugby players, since increased VO_2max improves overall physical performance and rapid recovery after intense exercise.

There was also a 4.8% increase in max V_E, indicating improved respiratory efficiency and body’s ability to remove carbon dioxide and oxygenate blood during intense exercise more effectively.

Significant improvements in VO_2max kinetics, including a 7.3% reduction in time needed to reach 50% of max V_E ($T_{50}V_E$), indicate improved oxygen use efficiency and faster gains in aerobic power upon start of exercise.

Data show that the experimental training program facilitated a higher percentage of excess ventilation (% excess V_E), indicating better adaptation to aerobic workload as well as improved thermoregulatory mechanisms and oxygen metabolism.

One of the main outcomes of the training program was optimization of the response of the cardiorespiratory system to workloads approximated to maximum aerobic capacities of athletes. This demonstrates body’s improved adaptation to high intensity and the ability to maintain high levels of physical activity without significant fatigue.

A significant increase in the rate of development of cardiorespiratory system reactions indicates an improvement in aerobic function. This is especially important in a competition environment, where the ability to quickly adapt to changing conditions and maintain high work intensity without significant fatigue can be a critical factor for success.

A significant increase in the effectiveness of aerobic potential under conditions of increasing fatigue was identified, which indicates an increase in endurance of athletes and their ability to maintain high level of energy supply for a long time, especially in critical phases of competition activity.

In the control group that followed a traditional training program, no significant changes in the components of aerobic capacity were noticed, which emphasizes effectiveness of using a specialized training program to improve aerobic capacity.

The hypothesis that the use of a specialized training program aimed at stimulating cardiorespiratory system helps to increase aerobic function of the body of Rugby union athletes has been confirmed. Effectiveness of the program was revealed in optimization of the heart rate response at workloads approaching the zone of maximum manifestation of the athletes’ aerobic capabilities.

Table 2. Dynamics of indicators of aerobic energy supply reactions of qualified rugby players during the experiment

N	Indicators	Registration conditions	Experimental group (n = 15)		Control group (n = 15)		Δx	t	Sig.	95% Confidence interval of the difference between the means	
			X	s	X	s				Lower limit	Upper limit
1	VO_2max ml·min^{-1}·kg^{-1}	before experiment	54.10	3.00	53.60	3.20	0.50	0.43	0.67	-1.819	2.819
		after experiment	54.90	1.10	54.00	1.10	0.90	2.16	0.04	0.077	1.723
2	max V_E (l/min)	before experiment	114.00	16.90	114.10	16.00	-0.10	0.02	0.98	-12.406	12.206
		after experiment	133.40	20.40	113.40	14.90	20.00	2.96	0.006	6.642	33.358
3	% excess V_E	before experiment	21.20	4.10	21.00	6.80	0.20	0.09	0.93	-3.999	4.399
		after experiment	24.90	2.80	20.90	4.10	4.00	3.01	0.005	1.375	6.625
4	$T_{50}V_E$ (s)	before experiment	31.90	8.90	32.00	12.70	-0.10	0.02	0.98	-8.301	8.101
		after experiment	24.70	9.10	32.90	11.20	-8.20	2.13	0.04	-15.831	-0.569
5	$T_{50}VO_2$, s	before experiment	35.00	9.60	34.60	9.90	0.40	0.11	0.91	-6.892	7.692
		after experiment	26.10	7.60	31.70	6.70	-5.60	2.07	0.047	-10.958	-0.242
6	t VO_2(±2 ml·min^{-1}·kg^{-1}VO_2 "plateau"), s	before experiment	22.00	6.80	24.00	6.90	-2.00	0.77	0.45	-7.123	3.123
		after experiment	47.20	5.10	28.20	6.10	19.00	8.94	0.0001	14.796	23.204
7	V'_E TAM*, l·min^{-1}	before experiment	72.90	13.60	73.10	13.80	-0.20	0.04	0.97	-10.445	10.045
		after experiment	99.10	12.10	79.10	12.00	20.00	4.39	0.0001	10.989	29.011
8	$V'O_2$TAM ml·min^{-1}.kg^{-1}	before experiment	40.00	2.90	38.70	6.00	1.30	0.73	0.48	-2.224	4.824
		after experiment	45.20	2.00	41.30	6.00	3.90	2.31	0.03	0.556	7.244

* Threshold of Anaerobic Metabolism

Table 3. Dynamics of indicators of aerobic energy supply reactions of qualified rugby players experimental group during the experiment

N	Indicators	Before experiment		After experiment		Δx	t	Sig.	95% Confidence interval of the difference between the means	
		X	s	X	s				Lower limit	Upper limit
1	VO_2max ml·min^{-1}·kg^{-1}	54.10	3.00	54.90	1.10	0.80	0.94	0.36	-0.890	2.490
2	max V_E (l/min)	114.00	16.90	133.40	20.40	19.40	2.74	0.011	5.392	33.408
3	% excess V_E	21.20	4.10	24.90	2.80	3.70	2.79	0.009	1.075	6.325
4	$T_{50}V_E$ (s)	31.90	8.90	24.70	9.10	-7.20	2.12	0.04	-13.931	-0.469
5	$T_{50}VO_2$, s	35.00	9.60	26.10	7.60	-8.90	2.72	0.011	-15.375	-2.425
6	t VO_2(±2 ml·min^{-1}·kg^{-1}VO_2 "plateau"), s	22.00	6.80	47.20	5.10	25.20	11.09	0.0001	20.705	29.695
7	V'_E TAM*, l·min^{-1}	72.90	13.60	99.10	12.10	26.20	5.39	0.0001	16.574	35.826
8	$V'O_2$TAM ml·min^{-1}.kg^{-1}	40.00	2.90	45.20	2.00	5.20	5.52	0.0001	3.337	7.063

* Threshold of Anaerobic Metabolism

The findings prove the scientific comprehension of how specialized training programs can optimize aerobic capacity and overall physical performance of athletes in team sports such as rugby, where aerobic endurance and power play a key role in successful competition activity.

The implementation of the innovative training methodology aimed at optimization of kinetics of aerobic energy metabolism and maximization of functionality of cardiovascular and respiratory systems demonstrates statistically confirmed improvement in indices of maximum oxygen consumption (VO_2max), maximum lung ventilation (max V_E), as well as oxygen use efficiency at the level of kinetic characteristics of achieving VO_2max. These modifications of physiological parameters indicate a significant strengthening of

Table 4. Dynamics of indicators of aerobic energy supply reactions of qualified rugby players control group during the experiment

N	Indicators	Before experiment		After experiment		Δx	t	Sig.	95% Confidence interval of the difference between the means	
		X	s	X	s				Lower limit	Upper limit
1	VO_2max ml·min^{-1}·kg^{-1}	53.60	3.20	54.00	1.10	0.40	0.44	0.67	-1.389	2.189
2	max V_E (l/min)	114.10	16.00	113.40	14.90	-0.70	0.12	0.91	-12.261	10.861
3	% excess V_E	21.00	6.80	20.90	4.10	-0.10	0.05	0.96	-4.299	4.099
4	$T_{50}V_E$ (s)	32.00	12.70	32.90	11.20	0.90	0.20	0.84	-8.054	9.854
5	$T_{50}VO_2$, s	34.60	9.90	31.70	6.70	-2.90	0.91	0.38	-9.221	3.421
6	t VO_2(±2 ml·min^{-1}·kg^{-1}VO_2 "plateau"), s	24.00	6.90	28.20	6.10	4.20	1.71	0.11	-0.670	9.070
7	V'_E TAM*, l·min^{-1}	73.10	13.80	79.10	12.00	6.00	1.23	0.24	-3.670	15.670
8	$V'O_2$TAM ml·min^{-1}.kg^{-1}	38.70	6.00	41.30	6.00	2.60	1.15	0.27	-1.887	7.087

* Threshold of Anaerobic Metabolism

adaptation processes in the body of athletes, which leads to an increase in their aerobic power and endurance, as well as to more effective recovery after high-intensity exercise.

Thus, the achieved results emphasize importance of an individualized approach in the development of training programs for high-level athletes, assuming the need for further research of the mechanisms of adaptation to aerobic exercise and their optimization to improve sports performance. These findings may serve as the basis for the development of innovative training strategies aimed at maximization of aerobic potential of athletes, which opens new horizons in sports medicine and physiology of higher nervous activity.

Discussion

Our research has confirmed the hypothesis that the use of a specialized program of training aids aimed at stimulating the cardiorespiratory system helps to increase the aerobic function of the body of the rugby union athletes. The effectiveness of the program has been manifested in the optimization of the heart rate (HR) response when performing loads close to the zone of maximum manifestation of the' aerobic capabilities of the athletes. These changes indicate an increase in the functional capabilities of the athletes, which, in turn, indicates the dominant influence of aerobic energy supply with a reduced influence of glycolytic processes.

As a result of the application of the training means program, it can be stated that the increase in the aerobic function of the body occurred due to the stimulation of the cardiorespiratory system of the body. This is evidenced by the optimization of the heart rate response under conditions of load intensity close to the zone of maximum manifestation of aerobic capabilities of athletes (Pastor et al., 2023; Waldron et al., 2023).

Optimization of the cardiorespiratory system is associated with an increase in the number of peak values of the heart rate response close to the level of MROC and an increase in the stability of the achieved levels of function during this period (Meir et al., 2023). Available tendency towards a linear increase of function indicates the dominant influence of aerobic energy supply under conditions of a reduced influence of glycolytic processes. These findings confirmed the results of changes in the rate of reaction development. A significant increase in the rate of development of rugby players' responses under the influence of special training means was noted.

The increase of functional capabilities of rugby players is shown by the increase of reactions that characterize various aspects of the aerobic potential of athletes, which is confirmed by Colosio AL et al. (Colosio et al., 2018). To a greater extent, these changes concerned those aspects of aerobic capabilities of athletes that influenced the performance of rugby players in the zone of anaerobic metabolism threshold and under conditions of growing fatigue in the process of competition activity.

An analysis of the structure of aerobic capabilities of qualified rugby players and its manifestations in the process of competition activity gives reason to state that activation of neurogenic, "acute" hypoxic and complex neurogenic and acidemic reaction stimuli can be a factor in improvement of functional capabilities of athletes (Pramkratok et al., 2022).

The results of using the program of training means aimed at stimulating the cardiorespiratory system of the body. The kinetics of the heart rate reaction has been analyzed. The initial part of the heart rate reaction, which was determined by the speed of development of the reaction has a close connection with the speed of development of aerobic energy supply reactions and objectively reflects the reactive properties of the cardiorespiratory system (Korobeynikova et al., 2018; Iso et al., 2023).

Increasing the speed of development of the cardiorespiratory system creates conditions for achieving peak reaction values, increases the share of economical aerobic energy supply in the overall energy balance to support performance of athletes (Rovniy et al., 2017; Diachenko, et al., 2020; Tyshchenko et al., 2020). An increase in the kinetics of reactions of the cardiorespiratory system is one of the objective indicators of a positive change in the function of aerobic energy supply as a response to special loads (Mishchenko et al., 2009; Sado et al., 2023). The use of conditions for the implementation of these reaction stimuli allows the development of functions of the cardiorespiratory system with anaerobic glycolytic energy supply not been actively used in the work, which is a requirement for improvement of aerobic capabilities of athletes. Strengthening the role of these factors will enble to better form both mobilization and implementation components of endurance, in relation to specific conditions of body fatigue, in the process of competition activity of athletes in Rugby union (Naughton et al., 2023; Scott et al., 2022).

The use of the program has led to a significant increase in the speed of development of reactions of the cardiorespiratory system, which is an important indicator of improvement of aerobic function. This is especially important within the competitive conditions, where the ability to adapt quickly to changing conditions and maintain high intensity of work without significant fatigue can become a decisive factor for success.

The increase in functional capabilities in the anaerobic metabolism threshold zone has been also noted, which indicates an increased efficiency of aerobic potential in conditions of increasing fatigue. These results highlight the importance of aerobic fitness for the athletes participating in sports with high aerobic demands, such as Rugby union.

The multilevel analysis demonstrates how specific training interventions, including neurogenic and hypoxic stimulation, can optimize adaptive mechanisms of the cardiorespiratory system of athletes. This approach differs from traditional methods presented in previous researches (Rovniy et al., 2017), due to its ability to target specifically improvements in the metabolic efficiency and aerobic power of athletes, which represents a significant addition to the doctrinal provisions in the field of sports physiology. Our research expands the understanding of physiological adaptations to extreme training conditions and offers an innovative methodology for improving the functional performance of rugby players based on an integrated approach to the preparation process.

So Rovniy, A. et al. focused on the effect of normobaric interval hypoxic training, depending on the playing position of the players. We have added to existing knowledge by showing that a specific training program can lead to the significant improvements in aerobic performance and endurance of the athletes, which highlights the importance of an individualized approach to the preparation process in rugby.

The results of rugby players testing from the experimental group showed significant changes in the reactions of aerobic energy supply under the influence of a special training program. With athletes of the experimental group, the most significant changes were noted in terms of the kinetics and stability of reactions; the indicators of O_2 consumption and pulmonary ventilation in the intensity zone of the anaerobic metabolism threshold significantly increased. A tendency towards an increase in indicators that characterize the power of the respiratory response (max V_E), including the ones under conditions of increasing fatigue (% excess V_E) was observed. At the same time, no significant changes in the power of the O_2 consumption reaction (VO_2max) were observed. With the athletes of the control group, no significant changes in the indicators of the components of aerobic capacity were observed. The data presented indicate the development of aerobic capabilities in the zone of anaerobic metabolism threshold and an increase in the efficiency of aerobic potential realization under conditions of growing fatigue (McNeill et al., 2021).

The results suggest that rugby training imposes high aerobic demands, which may be too high in addition to strength training and therefore limit optimal endurance development (Chtara et al., 2005). These indicators largely reflect the specialized manifestations of the aerobic capabilities of rugby players and influence on the increase of special functional capabilities of athletes, as indicated by studies of high-level rugby players in China (Fu et al., 2019). The authors found that the aerobic power is different between the forwards and the defenders, but the power of aerobic of Chinese players is weaker than that of the foreign rugby players. This has been proved by the results of the analysis of urgent adaptive reactions recorded in model conditions of competition activity (Luginbühl et al., 2023; Twist & Highton, 2023). However, scientists found no effect of strength training on endurance performance (VO_2max) in studies of team sports players (Ignjatovic et al., 2011). The increase in the kinetics and stability of aerobic energy supply reactions and relatively reduced rates of increase in MROC are logical from the point of view of the direction of additional stimulating effects (Doma et al., 2019). To develop MROC, modes of motor activity of submaximal intensity and training sessions with a high load are usually used.

Our approach demonstrates an in-depth understanding of the specific physiological mechanisms underlying adaptations to rugby training, while the research by O'Gorman, D. Et al. emphasizes the value of using field tests to assess aerobic function (O'Gorman et al., 2000).

The results we have obtained stand out due to the understanding of aerobic adaptations of rugby players, adding to existing knowledge of physical fitness in the sport (Colosio et al., 2018; Fu et al., 2019).

In contrast to the generally accepted view of the predominant effect of anaerobic training on the performance of rugby players (Söyler et al., 2024), our research highlights the importance of aerobic training and its specific effect on improving aerobic capacity, especially in the anaerobic threshold zone, without a noticeable increase in maximum oxygen consumption. This expands the understanding of training approaches to improve endurance and aerobic performance of high-level athletes (Chtara et al., 2005; Doma et al., 2019; Booth et al., 2020).

We also emphasize the importance of aerobic fitness to improve the performance capabilities of rugby players. The scientists have confirmed that aerobic fitness plays a key role in improving endurance on the rugby field, and includes the development of aerobic power (Gabbett, 2005) and lactate tolerance (Gabbett, 2006; Hurley et al., 1984; Taylor et al., 2021), which is crucial for effective recovery from anaerobic efforts in the game.

The experts emphasize the importance of aerobic endurance for improving gaming performance. Aerobic power and lactate tolerance are key components needed to maintain high levels of energy production during play and recovery from anaerobic efforts. It is suggested the use of various training methods such as steady tempo (Rennie et al., 2021; Gabbett & Masters, 2011), interval training (Tian, 2022; Vachon et al., 2022) and special endurance (Camillini et al., 2018; Senavirathna et al., 2021), to develop these components, which complements our research on aerobic adaptations in rugby.

We have described the use of specialized training programs to achieve improvements in aerobic performance of rugby players. The authors confirm that various training methods are used to develop aerobic endurance, including interval training and specialized exercises that simulate real-life match conditions (Pastor et al., 2023) It is indicated that training approaches can vary significantly and must be adapted to the specific needs of athletes, as stated by a number of experts (Mellalieu et al., 2023; Fazackerley et al., 2023).

Our research focuses on the fact that aerobic demands may differ depending on playing position. Similar findings have made by a team of specialists that considered the physiology of aerobic exercise of professional rugby players, where it has been found that attackers and defenders have different levels of aerobic fitness (Hu et al., 2022; Hart et al., 2023), highlighting the need for individualized training programs (Zabaloy et al., 2020; Scott et al., 2023; Taylor et al., 2021).

Our article is complemented and supported by the findings of the specialists, regarding the effects of aerobic training on rugby players. Thus, a study conducted by Julien Robineau and his colleagues shows that recovery between strength and aerobic training affects adaptation to combined training (Robineau et al., 2016). They found out that training without a break between strength and aerobic sessions (C-0h), and to a lesser extent, training twice a day (C-6h), was not optimal for improving neuromuscular and aerobic performance, highlighting the importance of planning the preparation process to achieve full adaptive response to combined training. We have added to existing knowledge demonstrating that a targeted combination of specific stimulation can improve effectively the aerobic performance of rugby players, suggesting new techniques for enhancing athletic performance, while the reviewed study by Julien Robineau et al. highlights the importance of recovery time between strength and aerobic sessions to maximize increase in strength and aerobic performance power.

We have presented an innovative approach to the preparation process of rugby players, including neurogenic and hypoxic stimulation to improve aerobic capacity. Unlike previously studied methods by the Scott, A.C. et al., where they emphasized on assessing the aerobic physiology of professional rugby players through standardized maximal oxygen uptake tests, our approach adds to existing knowledge by providing a technique that not only increases aerobic performance indicators, but also maskes this with the help of specific, targeted stimulation. This provides additional training opportunities based on physiological adaptations to exercise, increasing understanding of how rugby performance can be effectively improved (Scott et al., 2003).

Thus, our research and information from other specialists complement each other, emphasizing the importance of aerobic training in rugby, confirming that aerobic training should take into account the specifics of the sport, playing positions and individual characteristics of athletes to achieve optimal results.

Our research contributes to the specialized field of sports science by introducing an innovative approach to training for rugby players, focusing on the endogenous stimulation of cardiorespiratory adaptation through a synergistic combination of neurogenic activation and controlled hypoxic exposure. This methodology opens up the new perspectives for optimizing the physiological potential of athletes, providing an evidence base for the effectiveness of managing the adaptive reactions of the body under conditions of variable oxygen content, which, in turn, helps to increase aerobic capacity and improve the overall endurance of athletes at a highly competitive level.

Our research makes a significant contribution to the field of sports science by focusing on optimizing aerobic function of rugby players through tailored training approaches. It demonstrates how systematic stimulation of the cardiorespiratory system using neurogenic, "acute" hypoxic and acidemic stimuli can effectively increase the kinetics and sustainability of aerobic energy supply responses without causing significant acidemic changes in the body. This highlights the importance of integrating such training regimens into preparatory programs to improve the specific functional capabilities of rugby players, especially in the context of increasing aerobic capacity and performance under increasing fatigue conditions. The practical significance of the research lies in its potential to serve as the basis for the development of training programs that specifically influence the improvement of gaming endurance and general physical fitness of the athletes, which can directly affect their sporting achievements at the professional level.

Activation of neurogenic, "acute" hypoxic and acidemic stimuli through a specially designed training program has provided positive effects on aerobic capacity and fatigue resistance of the Rugby union athletes. These findings can be used to further development training methods aimed at improving athletic performance.

Due to the introduction of our experimental program in the preparation process, the Ukrainian national team eventually took 2nd place at the European Rugby union Championship in the Trophy division of the 2022-2023 season.

Conclusions

The study's conclusions of the study affirm the effectiveness of a specially devised training program aimed at augmenting the aerobic energy system's responsiveness in rugby union athletes. Through methodical application, the program significantly enhanced athletes' aerobic capacities, particularly under conditions straddling the anaerobic threshold and elevated fatigue levels. This was evidenced by the experimental group's superior performance metrics in comparison to a control group adhering to conventional training paradigms. These findings not only underscore the potential for tailored training interventions to optimize aerobic performance but also highlight their pivotal role in elevating competitive prowess, as exemplified by the Ukrainian National Rugby union team's accomplishments at the European Championship.

The prospects for further research in this field should focus on the longitudinal assessment of the training program's impact on the athletes' performance across multiple competitive seasons. Investigating the program's adaptability and effectiveness across different athletic disciplines could also yield valuable insights. Additionally, exploring the psychological aspects of endurance and performance under stress, as well as the integration of technology and data analytics for personalized training regimes, could further enhance the understanding and application of aerobic energy system optimization in sports.

Conflicts of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and publication of this article.

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Стимуляція реакцій аеробного енергопостачання спортсменів у регбі-15

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

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Мета дослідження – перевірити ефективність експериментальної програми тренувальних засобів, спрямованих на стимуляцію реакцій аеробного енергозабезпечення спортсменів, які входять до складу національної збірної України з регбі-15.

Матеріал і методи. Спортсмени збірної України з регбі-15 були розподілені на дві однорідні групи (експериментальну та контрольну) по 15 осіб. Експериментальна група займалася за розробленою програмою, що спрямована на розвиток аеробного енергозабезпечення, тоді як контрольна група – за стандартною програмою тренувань. Об'єкт дослідження – навчально-тренувальний процес національної збірної України з регбі-15.

Результати. Результати тестування регбістів експериментальної групи продемонстрували достовірні зміни реакцій аеробного енергозабезпечення під впливом програми спеціальних тренувань. Найбільш суттєві зміни відзначені в показниках кінетики та стійкості реакцій, достовірно підвищилися показники споживання O_2 та легеневої вентиляції в зоні інтенсивності порогу анаеробного обміну. Спостерігалася тенденція до підвищення показників, що характеризують потужність дихальної реакції (max V_E), зокрема в умовах наростаючої втоми (% перевищення V_E). У спортсменів контрольної групи суттєвих змін показників компонентів аеробних можливостей не було.

Висновки. Вважаємо, що зазначені показники здебільшого відображають спеціалізовані прояви аеробних можливостей регбістів, і впливають на підвищення їх спеціальних функціональних можливостей, що підтверджено результатами аналізу термінових адаптаційних реакцій, зареєстрованих у модельних умовах змагальної діяльності. Результатом реалізації зазначеної експериментальної програми в процесі підготовки стало II місце збірної України на Чемпіонаті Європи з регбі-15 у дивізіоні Трофі сезону 2022-2023 років.

Ключові слова: регбі, аеробне енергозабезпечення, кардіореспіраторна система, експериментальна тренувальна програма.

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