REPORTS OF MORPHOLOGY

*Official Journal of the Scientific Society of Anatomists,
Histologists, Embryologists and Topographic Anatomists
of Ukraine*

journal homepage: <https://morphology-journal.com>

Comparative characteristics of changes in central hemodynamics during early recovery after different exercise regimes

Lukyantseva H.V., Bakunovsky O.M., Malyuga S.S., Oliynyk T.M., Manchenko N.R., Manchenko Y.R., Korolyova D.O.

National University of Ukraine on Physical Education and Sport, Kyiv, Ukraine

ARTICLE INFO

Received: 24 February 2021

Accepted: 14 April 2021

UDC: 612.13:613.73(045)

CORRESPONDING AUTHOR

e-mail: lukjantseva@gmail.com

Lukyantseva H.V.

The cardiovascular system is one of the most important functional systems of the body, which determine the level of physical performance of the body. Insufficient study of the response of the circulatory system to the combination of strength training with endurance exercises requires more detailed comparative studies of the impact of dynamic and static loads on the indicators of central hemodynamics. Accordingly, the aim of our study was to study the characteristics of the reaction of the cardiovascular system in the period of early recovery after dosed exercise of a dynamic and static nature. The study examined the response of the central hemodynamics of young men in the period of early recovery after dynamic loading (Martine functional test) and static loading (holding on the stand dynamometer DS-200 force with a power of 50% of maximum standing force). The change in circulatory system parameters was recorded using a tetrapolar thoracic impedance rheoplethysmogram on a computerized diagnostic complex "Cardio +". It is established that the dynamic load in the period of early recovery does not cause a significant positive chronotropic effect, leads to a decrease in vascular resistance of blood flow, to an increase in pulse blood pressure. The increase in cardiac output is mainly due to the increase in stroke volume, which indicates a fairly high functional reserves of the heart. It is revealed that under conditions of static loading the reaction of central hemodynamics and the course of early recovery are radically different from the changes of indicators under dynamic loading. In persons with a normodynamic type of reaction to dynamic load, there are no significant changes in the minute volume of blood at a similar volume of active muscle mass static load. Meeting the metabolic needs of working skeletal muscles and compensating for the oxygen debt is realized by increasing the total peripheral vascular resistance and increasing systolic blood pressure in the postpartum period. The physiological meaning of this phenomenon is to maintain a sufficient level of venous return of blood to ensure the pumping function of the heart.

Keywords: cardiovascular system, dynamic loading, static loading, recovery.

Introduction

One of the most important functional systems of the body, which largely determines and limits the physical performance of the body, is the circulatory system. Adaptation of the cardiovascular system (CVS) to different modes of physical activity is one of the central issues of the whole problem of adaptation because the ability of this system to increase its function often becomes the link that significantly limits the intensity and duration of adaptive responses [9, 10, 18, 24].

Modern non-professional areas of physical fitness, as well as sports of higher achievements are characterized

by a significant increase in the intensification of training loads, which is dictated by the desire of athletes to achieve the highest sports results [13, 14, 15]. However, the marked increase in volume, duration and intensity of physical activity without proper consideration of individual features of adaptation to them can lead to prepathological and, sometimes, even to pathological changes of activity of heart and blood vessels (arrhythmia, hypertrophic cardiomyopathy, myocardial dystrophy, coronary artery pathology, myocarditis, etc.) [16, 20], which without proper consideration of the functional aspects of the adaptation of

the cardiovascular system can cause deaths during sports [6, 19].

Intense muscular work leads to a significant increase in the load on the circulatory system, resulting in the formation of structural and functional changes in the heart, which are combined into the general concept of "sports heart". The establishment of diagnostic criteria for this syndrome continues to this day, due to the search for markers of myocardial damage, risk factors for cardiac pathology and predictors of sudden cardiac death, etc. [8, 10, 19, 22].

Regular physical activity of static, static-dynamic and dynamic nature causes specific adaptive changes in the circulatory system. Electro-morphological remodeling of the sports heart, which occurs, together with its functional restructuring inevitably lead to changes in the injection function and, as a consequence, to systemic changes in a number of indicators of central and peripheral hemodynamics [1, 6, 8].

Fitness training as a type of physical activity, optimally combines dynamic and strength training loads. This approach involves testing the level of physical performance of a person, in particular, determining the parameters of the response of central hemodynamics to the combination of a set of strength loads with endurance exercises. Insufficient study of these issues requires more detailed comparative studies of the impact of dynamic and static loads on the performance of the circulatory system.

The aim of our study was to study the features of the central hemodynamic response in the period of early recovery after dosed physical activity of dynamic and static nature.

Materials and methods

The presented work is a fragment of research work of the Department of Medical and Biological Disciplines of the National University of Physical Education and Sport of Ukraine "Influence of exogenous and endogenous factors on the course of adaptive reactions of the body to physical activity of varying intensity" (state registration number 012U108187).

The study involved practically healthy male adolescents (21 years) without bad habits, 4th year students of NUUPES, direction of training "Sports" (examined 24 volunteers, average height - 175.0 ± 4.0 cm, average body weight 69.20 ± 1.10 kg). The study of the subjects was performed in the morning 1-2 hours after a meal, after the arrival of the subject to the laboratory at least 15 minutes of passive rest (in order to eliminate potential stress effects on the cardiovascular system). The examination protocol included information on the date and time of the examination, sex and age (date of birth) of the subject, features of physical activity for the last 3 months.

The study was conducted in two stages. In the first stage, the course of changes in central hemodynamics in the period of early recovery after dynamic loading (DL) and determined the type of response of the cardiovascular system to the functional Martine test (test with 20 squats for 30 seconds),

modified for use as a functional test with dynamic load. Before exercise, the heart rate (HR) was counted for 10 seconds by palpation on the left carotid artery, blood pressure was measured in the right upper extremity by the method of Korotkov and, simultaneously with blood pressure measurement, recorded tetrapolar thoracic impedance rheoplethysmogram (TRP) "Cardio+" complex (Ukraine). For the first ten seconds after exercise, the heart rate in the left carotid artery was counted. In the next 40 seconds, blood pressure was measured and TRP was recorded. Next, during the last 10 seconds of the first minute of recovery, heart rate was counted. The above examination was repeated in the second and third minutes of recovery. During the examination, the subject was in a standing position.

The second stage of the study began 15 minutes after the first. In the second stage, the response of the cardiovascular system to the dosed static load (SL) was determined. For the second stage of the study, only individuals with a normotonic type of reaction were selected. The students (20 people) involved in this stage were randomly (randomly) divided into 2 groups: control (Gr.1, 10 people) and main (Gr.2, 10 people). In both groups with the help of a stand-up dynamometer DS-500, 5 minutes before the functional test with static load, determined the maximum arbitrary standing force. As a sample with a static load in Gr.2 used the hold on the stand dynamometer DS-200 for 15 seconds, the force level, which corresponded to 50% of the maximum standing force. The countdown of the holding time began from the moment of fixing the force on the corresponding mark of the dynamometer. In Gr.1 - simulated the corresponding static force by holding on the stand dynamometer DS-200 for 15 seconds, the level of effort, which corresponded to 10% of the maximum standing force, which should not cause significant force and shifts in the visceral systems of the body [3, 20, 18]. Subjects in both groups and researchers who recorded CVS performance were not informed about the level of effort held by a particular subject. The dynamometer readings were monitored by a separate researcher-controller. Registration of CVS performance indicators was performed in the same sequence and by the same methods as in the sample with dynamic loading until full recovery.

The following indicators of central hemodynamics were evaluated: heart rate (HR), systolic blood pressure (sBP), diastolic blood pressure (dBP), pulse blood pressure (pBP), mean dynamic blood pressure (adBP), stroke volume (SV), minute blood volume (MVB), total peripheral vascular resistance (TPVR).

Statistical data processing was performed in the license package "Statistica 5.5" using non-parametric methods of evaluation of the obtained results.

Results

At the first stage of the study, 24 volunteers were examined. A normotonic reaction to a functional test was found in 20 people, a hypotonic type of reaction was

Table 1. The average values of central hemodynamics in the period of early recovery ($M \pm \sigma$).

indicator	Before DL	1 min after DL	2 min after DL	3 min after DL
HR, b/s	74.11 $\pm$ 3.02	86.08 $\pm$ 2.04*	77.06 $\pm$ 2.03	77.15 $\pm$ 1.02
sBP, mm Hg	121.3 $\pm$ 3.2	130.3 $\pm$ 3.1*	132.2 $\pm$ 1.14*	125.1 $\pm$ 1.15
dBp, mm Hg	67.09 $\pm$ 2.18	63.60 $\pm$ 2.21	64.05 $\pm$ 1.09	66.04 $\pm$ 2.08
pBP, mm Hg	55.08 $\pm$ 2.11	67.39 $\pm$ 1.08*	67.01 $\pm$ 1.02*	57.23 $\pm$ 2.13
adBP, mm Hg	84.31 $\pm$ 3.14	85.16 $\pm$ 2.03	86.06 $\pm$ 1.04	85.11 $\pm$ 2.03
SV, ml	79.14 $\pm$ 3.11	92.13 $\pm$ 2.08*	80.08 $\pm$ 2.06	78.06 $\pm$ 3.04
MVB, l/min	5.632 $\pm$ 0.224	7.902 $\pm$ 0.092*	6.052 $\pm$ 0.152	5.821 $\pm$ 0.122
TPVR, dyn *s/cm ⁵	1213 $\pm$ 14	888.2 $\pm$ 11.1*	1159 $\pm$ 12	1196 $\pm$ 13

Notes: * - reliable in relation to the condition before load ($p < 0.05$).

established in 3 people, and a hypertensive in one. For the analysis of changes in central hemodynamics after dynamic exercise, only the data obtained in the study of individuals with a normotonic response to the Martin test were selected. The average values of central hemodynamics in the period of early recovery are shown in Table 1.

Immediately after exercise in a dynamic mode, an increase in heart rate by 15%, as well as a moderate increase in systolic blood pressure and a slight decrease in diastolic pressure, which, in turn, caused an increase in pulse blood pressure by 22%. No statistically significant changes in mean dynamic pressure were recorded. Stroke volume increased by an average of 16% during dynamic exercise and minute blood volume increased by 40%. The total peripheral resistance during physical activity in the dynamic mode decreased and at the first minute of recovery was 73% of the value of TPVR to the load. In all surveyed students, the recovery of the circulatory system to its original state occurred 2-3 minutes after dynamic exercise.

The response of central hemodynamics to static load

was analyzed by comparing the course of early recovery in Gr2 and Gr1. The average values of central hemodynamics in the period corresponding to the period of early recovery after dosed static exercise are shown in table 2.

In the main group (Gr.2) immediately after static load, the level of sBP increased by an average of 15 mm Hg, which led to an increase in pulse blood pressure by 35% and a tendency to increase TPVR. In Gr1 in the corresponding period after static loading there was only a statistically insignificant tendency to increase sBP, pBP and adBP. In the first minute after exercise, the changes in sBP and pBP that took place in Gr.2 were significant relative to the values of these indicators in Gr1. Complete recovery of blood pressure in Gr2 occurred 4 minutes after SL.

At 1 and 2 minutes after static loading, there were no statistically significant changes in heart rate, SV and MVB in both groups. However, in Gr.2 in the first minute there was a tendency to decrease SV along with tendencies to increase heart rate and MVB, and in the third minute - in Gr.2 registered a statistically significant increase in heart rate and decrease SV relative to the initial state of Gr.2 and values in Gr.1 at the specified time. These changes in heart rate and SV were combined with a tendency to decrease MVB compared with the value of the indicator at 1 and 2 minutes. However, at the third minute, the value of MVB in Gr2 approached the initial level and did not differ from the value of MVB in the control.

In Gr.1 TPVR remained unchanged. In Gr.2 registered progressive from 1 to 3 minutes growth of TPVR. As a result, the total vascular resistance of blood vessels increased by 7% relative to the state to static load and exceeded the value of the indicator in Gr.1 in the corresponding recovery period by 6%. Recovery in terms of heart rate, SV and TPVR in Gr. 2 occurred in the 5th minute after SL.

Discussion

Dosed physical activity during a standard functional Martin test did not cause a significant positive chronotropic effect, and the growth of MVB was provided mainly by an increase in SV, which is a manifestation of a high degree of

Table 2. The average values of central hemodynamics in the period of early recovery after dosed static exercise ($M \pm \sigma$).

		HR	sBP	dBp	pBP	adBP	SV	MVB	TPVR
		b/s	mm Hg				ml	l/min	dyn *s/cm ⁵
Before DL	Gr 1	73.27 $\pm$ 3.12	125.2 $\pm$ 3.1	81.04 $\pm$ 1.08	45.07 $\pm$ 3.07	95.04 $\pm$ 2.04	80.07 $\pm$ 2.02	5.682 $\pm$ 0.104	1290 $\pm$ 12
	Gr 2	74.11 $\pm$ 3.09	128.1 $\pm$ 3.2	80.09 $\pm$ 1.02	47.11 $\pm$ 2.08	96.04 $\pm$ 2.03	79.13 $\pm$ 3.04	5.682 $\pm$ 0.206	1283 $\pm$ 13
1 min after DL	Gr 1	74.09 $\pm$ 2.09	130.2 $\pm$ 4.8	79.05 $\pm$ 2.04	50.03 $\pm$ 2.03	98.02 $\pm$ 1.02	79.01 $\pm$ 1.02	5.683 $\pm$ 0.203	1303 $\pm$ 11
	Gr 2	80.04 $\pm$ 2.03	143.2 $\pm$ 3.2**	78.09 $\pm$ 2.04	65.07 $\pm$ 1.08**	100 $\pm$ 1	75.06 $\pm$ 3.04	5.963 $\pm$ 0.202	1326 $\pm$ 10*
2 min after DL	Gr 1	72.04 $\pm$ 3.03	130.2 $\pm$ 3.2	80.07 $\pm$ 2.06	50.05 $\pm$ 3.04	98.03 $\pm$ 2.02	77.02 $\pm$ 3.02	5.792 $\pm$ 0.201	1302 $\pm$ 11
	Gr 2	77.04 $\pm$ 3.14	135.2 $\pm$ 2.4*	80.14 $\pm$ 1.09	55.12 $\pm$ 2.07	98.09 $\pm$ 1.05	76.07 $\pm$ 1.03	5.842 $\pm$ 0.202	1347 $\pm$ 9**
3 min after DL	Gr 1	73.17 $\pm$ 2.13	126.4 $\pm$ 3.4	80.07 $\pm$ 1.08	46.06 $\pm$ 3.07	95.04 $\pm$ 3.05	78.07 $\pm$ 1.03	5.653 $\pm$ 0.203	1298 $\pm$ 12
	Gr 2	83.16 $\pm$ 1.09**	130.6 $\pm$ 2.1	79.14 $\pm$ 2.1	51.12 $\pm$ 3.07	96.19 $\pm$ 3.04	68.09 $\pm$ 3.07**	5.612 $\pm$ 0.202	1370 $\pm$ 9**

Notes: * - reliable in relation to the condition before loading ($p < 0.05$); + - reliably relative to the control group ($p < 0.05$).

functional reserves of the heart [1, 4]. These reserves are due to increased heart rate (due to physiological hypertrophy of the left ventricular myocardium with a sufficient degree of capillarization) and physiological dilatation of the heart chambers, in particular, the left ventricle, which provides the required end-diastolic volume [2, 12].

In our study, students with a normotonic type of response to the Martin test showed an increase in minute blood volume corresponding to the intensity of the load due to both an increase in SV and heart rate. However, heart rate remained within normocardia, which indicates a fairly high functional reserves of the heart. It should be noted that bradycardia was not observed at rest in the subjects.

Significant growth of sBP, too, may be evidence of increased left ventricular pumping function in trained students. The tendency to decrease the level of diastolic blood pressure, which was observed in response to dynamic loading, is the result of a decrease in the tone of resistive vessels, which may be due to the release of biologically active substances - vasodilators, more beta- than alpha-adrenoreceptors and local temperature rise in actively working skeletal muscles [3, 9]. Reducing the tone of resistive vessels leads to their expansion in working muscles, which when performing dynamic physical exercises of a global nature (involving more than 50% of muscle mass) leads to a decrease in total peripheral vascular resistance [7, 11]. In our study, a significant decrease in TPVR was detected in the first minute after dynamic loading. From the second minute of recovery, the level of TPVR corresponding to the appropriate value of the indicator was registered. Note that rheography does not actually register the resistance of blood vessels; TPVR is defined as the ratio of mean-dynamic blood pressure (adBP) to cardiac output (ie, to MVB). During the Martin test, we did not find any significant changes in adBP. However, cardiac output increased, and TPVR, respectively, decreased, which is a physiologically appropriate response of the cardiovascular system to exercise [5, 17, 23].

Based on the analysis of the data obtained at the first stage of the study, we have reason to believe that the registration of TRP during the Martine test allowed a deeper study of the nature of the central hemodynamic response to DL and describe the physiological picture of hemodynamic response in normotonic response as follows: muscles, in particular, oxygen demand, should be provided by increase in MVB; reduction of vascular resistance of blood flow and increase of pulse blood pressure improve the state of perfusion of the capillary bed of working muscles, and the stability of adBP ensures optimal conditions for metabolism of water, nutrients and other components between blood and tissue fluid [1, 3, 13, 17, 21].

Under conditions of static loading lasting 15 seconds, the reaction of CG and the course of early recovery were radically different from the dynamics of CG during DL and in the control group. In individuals with a normodynamic type of response to DL, there were no significant changes in

MVB at a similar volume of active muscle mass static load, which is 50% of maximum strength. The dynamics of blood pressure indicators, which was characterized by a significant increase in sBP, was indicative. In our opinion, this may be due to the fact that with sufficient force of static load, the working muscles create external pressure on the vessels that pass through them. This primarily applies to the exchange vessels, where blood flow may stop altogether. In this case, some volume of blood can circulate through arterio-venous shunts [13, 14, 15]. The result will be a redistribution of circulating blood volume with an increase in blood volume in the arteries of the great circle of circulation, which is usually no more than 15% of the total circulating blood volume. Thus, it can be assumed that sBP increases in response to postload due to arterial hyperemia caused by mechanical obstruction of blood flow in tense muscles. The growth of TPVR in the first minute after SL can be explained by the same reasons as the growth of sBP.

However, in contrast to sBP, TPVR after the cessation of mechanical interference continues to grow within 2 and 3 minutes of the early recovery period. The probable reason for this, seemingly paradoxical fact, may be reactive hyperemia in ischemic muscles with significant static tension. It can be assumed that this increase in TPVR causes overflow of the microcirculatory region of the vascular bed, the cause of which lies, firstly, in the sharp relaxation of precapillary sphincters under the action of muscle metabolism and, secondly, increased venous tone as a compensatory response to limitation. blood flow into the venous bed during SL [3, 6, 7, 10]. The latter is aimed at maintaining a sufficient level of venous return to ensure the pumping function of the heart. Confirmation of our assumption that SL may lead to such a decrease in blood volume in the venous area of the great circle of circulation, which will require compensation, can be registered in the third and first minutes of the recovery period increase in heart rate in response to decreased SV. This is observed in orthostatic reactions, the cause of which is known to be a sharp decrease in venous return.

Conclusions

1. Dynamic loading during the Martin test in the period of early recovery leads to a decrease in vascular resistance of blood flow, to an increase in pulse blood pressure and to an increase in cardiac output, mainly due to the positive inotropic effect.

2. Under conditions of static load, the reaction of central hemodynamics and the course of early recovery are radically different from changes in dynamic loading.

3. In persons with a normotonic type of reaction to dynamic load, there were no significant changes in the minute volume of blood at a similar volume of active muscle mass static load. Meeting the metabolic needs of working muscles and compensating for oxygen debt are realized through post-work growth of total peripheral vascular resistance and increase in systolic blood pressure.

References

- [1] Badano, L., Kolias, J., Muraru, D., Abraham, T., Aurigemma, G., Edvardsen, T. ... Voigt, Jens-U. (2018). Standardization of left atrial, right ventricular, and right atrial deformation imaging using two-dimensional speckle tracking echocardiography: a consensus document of the EACVI/ASE/industry task force to standardize deformation imaging. *Eur. Hear J. Cardiovasc. Imaging*, 19(6), 591-600. doi: 10.1093/ehjci/ey042
- [2] Boraita, A., Heras, M., Morales, F., Marina-Breyse, M., Canda, A., Rabadan, M. ... Tunon, J. (2016). Reference values of aortic root in male and female white elite athletes according to sport. *Circ Cardiovasc Imaging*, 9(10), e005292. doi: 10.1161/CIRCIMAGING.116.005292.
- [3] D'Andrea, A., Formisano, T., Riegler, L., Scarafille, R., America, R., Martone, F. ... Calabro, R. (2017). Acute and Chronic Response to Exercise in Athletes: The "Supernormal Heart". *Adv Exp Med Biol*, 999, 21-41. doi: 10.1007/978-981-10-4307-9_2.
- [4] D'Ascenzi, F., Pisicchio, C., Caselli, S., Di Paolo, F., Spataro, A., & Pelliccia, A. (2017). RV remodeling in Olympic athletes. *JACC Cardiovasc Imaging*, 10(4), 385-393. doi: 10.1016/j.jcmg.2016.03.017
- [5] De la Garza, M., Carro, A., & Caselli, S. (2020). How to interpret right ventricular remodeling in athletes. *Clin. Cardiol.*, 43(8), 843-851. doi: 10.1002/clc.23350
- [6] Doleeb, S., Kratz, A., Salter, M., & Thohan, V. (2019). Strong muscles, weak heart: testosterone-induced cardiomyopathy. *ESC Heart Failure*, 6(5), 1000-1004. <https://doi.org/10.1002/ehf2.12494>
- [7] Domenech-Ximenes, B., la Garza, M., & Prat-Gonzalez, S. (2019). Exercise-induced cardio-pulmonary remodelling in endurance athletes: not only the heart adapts. *Eur. J. Prev. Cardiol.*, 27(6), 651-659. doi: 10.1177/2047487319868545
- [8] Fagerberg, P. (2018). Negative Consequences of Low Energy Availability in Natural Male Bodybuilding: A Review. *Int. J. Sport Nutr. Exerc. Metab.*, 28(4), 1, 385-402. doi: 10.1123/ijsnem.2016-0332
- [9] Fluck, M., Kramer, M., Fitze, D., Kasper, S., Franchi, M., & Valdivieso, P. (2019). Cellular Aspects of Muscle Specialization Demonstrate Genotype - Phenotype Interaction Effects in Athletes. *Front. Physiol.*, 8(10), 526. doi: 10.3389/fphys.2019.00526
- [10] Franchi, M., Reeves, N., & Narici, M. (2017). Skeletal Muscle Remodeling in Response to Eccentric vs. Concentric Loading: Morphological, Molecular, and Metabolic Adaptations. *Front. Physiol.*, 8, 447. doi: 10.3389/fphys.2017.00447
- [11] Gati, S., Sharma S., & Pennell, D. (2018). The role of cardiovascular magnetic resonance imaging in the assessment of highly trained athletes. *JACC Cardiovasc. Imaging*, 11(2P1), 247-259. doi: 10.1016/j.jcmg.2017.11.016
- [12] Koshy, S., Koshy, G., & Lekha, G. (2018). Changes in right ventricular morphology and function in athletes. *Echocardiography*, 35(6), 767-768. doi: 10.1111/echo.14027
- [13] Longstrom, J., Colenso-Semple, L., Waddell, B., Mastrofini, G., Trexler, E., & Campbell, B. (2020). Physiological, Psychological and Performance-Related Changes Following Physique Competition: A Case-Series. *J. Funct. Morphol. Kinesiol.*, 5(2), 27-35. doi: 10.3390/jfmk5020027
- [14] Korytko, Z., Kulitka, E., Bas, O., Chornenka, C., Zahidnyy, V., & Yakubovskiy T. (2020). Adequacy criteria of physical loadings and their use in sports, physical education, and physical rehabilitation. *Physical Education, Sport and Health Culture in Modern Society*, 50(2), 68-77. <https://doi.org/10.29038/2220-7481-2020-02-68-77>
- [15] Maden-Wilkinson, T., Balshaw, T., Massey, G., & Folland, J. (2020). What makes long-term resistance-trained individuals so strong? A comparison of skeletal muscle morphology, architecture, and joint mechanics. *J. Appl. Physiol*, 128(4), 1000-1011. doi: 10.1152/jappphysiol.00224.2019
- [16] Marrakchi, S., Kammoun, I., Bennour, E., Laroussi, L., Ben Miled M., & Kachboursa S. (2020). Inherited primary arrhythmia disorders: cardiac channelopathies and sports activity. *Herz*, 45(2), 142-157. doi: 10.1007/s00059-018-4706-2
- [17] Martinez, V., la Garza M., & Grazioli, G. (2019). Cardiac performance after an endurance open water swimming race. *Eur. J. Appl. Physiol.*, 119(4), 961-970. doi: 10.1007/s00421-019-04085-x
- [18] Martino, F., Perestrelo, A., Vinarsky, V., Pagliari, S., & Forte, G. (2018). Cellular Mechanotransduction: From Tension to Function. *Front. Physiol.*, 5(9), 824. doi: 10.3389/fphys.2018.00824
- [19] Mont, L., Pelliccia, A., Sharma, S., Biffi, A., Borjesson, M., Terradellas, J. ... La Gerche, A. (2017). Pre-participation cardiovascular evaluation for athletic participants to prevent sudden death: position paper from the EHRA and the EACPR, branches of the ESC. Endorsed by APhRS, HRS, and SOLAECE. *Eur. J. Prev. Cardiol.*, 24, 41-69. doi.org/10.1093/europace/euw243.
- [20] Pelliccia, A., Sharma, S., Gati, S., Back, M., Borjesson, M., Caselli, S. ... Wilhelm, M. (2021). Corrigendum to: 2020 ESC Guidelines on Sports Cardiology and Exercise in Patients with Cardiovascular Disease. *European Heart Journal*, 42(1), 17-96. doi: 10.1093/eurheartj/ehaa605
- [21] Qasem, M., George, K., Somauroo, J., Forsythe, L., Brown, B., & Oxborough, D. (2019). Right ventricular function in elite male athletes meeting the structural echocardiographic task force criteria for arrhythmogenic right ventricular cardiomyopathy. *J. Sports Sci.*, 37(3), 306-312. doi: 10.1080/02640414.2018.1499392
- [22] Radmilovic, J., D'Andrea, A., D'Amato, A., Tagliamonte, E., Sperlongano, S., Riegler, L., & Scarafille, R. (2019). Echocardiography in Athletes in Primary Prevention of Sudden Death. *J. Cardiovasc. Echogr.*, 29(4), 139-148. doi: 10.4103/jcecho.jcecho_26_19
- [23] Sanz, M., Garza, D., & Giraldeau, G. (2017). Influence of gender on right ventricle adaptation to endurance exercise: an ultrasound two-dimensional speckle-tracking stress study. *Eur. J. Appl. Physiol.*, 117(3), 389-396. doi: 10.1007/s00421-017-3546-8
- [24] Schoenfeld, B., & Grgic, J. (2018). Evidence-Based Guidelines for Resistance Training Volume to Maximize Muscle Hypertrophy. *Strength Cond. J.*, 40(4), 107-112. doi: 10.1519/SSC.0000000000000363

ПОРІВНЯЛЬНА ХАРАКТЕРИСТИКА ЗМІН ЦЕНТРАЛЬНОЇ ГЕМОДИНАМІКИ В ПЕРІОД РАНЬОГО ВІДНОВЛЕННЯ ПІСЛЯ РІЗНИХ РЕЖИМІВ ФІЗИЧНОГО НАВАНТАЖЕННЯ

Лук'янцева Г.В., Бакуновський О.М., Малуґа С.С., Олійник Т.М., Манченко Н.Р., Манченко Я.Р., Корольова Д.О.

Серцево-судинна система є однією з найважливіших функціональних систем організму, які визначають рівень фізичної працездатності організму. Недостатня вивченість реакції системи кровообігу на поєднання комплексу силових навантажень

із вправами на витривалість вимагає більш докладних порівняльних досліджень впливу динамічних і статичних навантажень на показники центральної гемодинаміки. Відповідно, метою нашого дослідження стало вивчення особливостей реакції серцево-судинної системи у період раннього відновлення після дозованих фізичних навантажень динамічного і статичного характеру. У дослідженні вивчали реакцію центральної гемодинаміки юнаків у період раннього відновлення після динамічного навантаження (функціональна проба Мартіне) і статичного навантаження (утримання на становому динамометрі ДС-200 зусилля потужністю 50% від максимальної станової сили). Зміну показників системи кровообігу реєстрували за допомогою тетраполяної грудної імпедансної реоплетизмограми на комп'ютеризованому діагностичному комплексі "Кардіо+". Встановлено, що динамічне навантаження у період раннього відновлення не викликає значного позитивного хронотропного ефекту, призводить до зменшення опору судин току крові, до збільшення пульсового артеріального тиску. Зростання хвилинного об'єму крові відбувається переважно за рахунок зростання ударного об'єму крові, що свідчить про достатньо високі функціональні резерви серця. Виявлено, що за умов статичного навантаження реакція центральної гемодинаміки і перебіг раннього відновлення кардинально відрізняються від змін показників при динамічному навантаженні. В осіб з нормодинамічним типом реакції на динамічне навантаження не відбувається суттєвих змін хвилинного об'єму крові при аналогічному за об'ємом активної м'язової маси статичному навантаженні. Забезпечення метаболічних потреб працюючих скелетних м'язів і компенсація кисневого боргу реалізуються за рахунок зростання загального периферичного опору судин і збільшення систолічного артеріального тиску у післяробочий період. Фізіологічний сенс означеного явища полягає у підтриманні належного рівня венозного повернення крові для забезпечення насосної функції серця.

Ключові слова: серцево-судинна система, динамічне навантаження, статичне навантаження, відновлення.