

KLAUDIA PALAK¹, AGATA FURGAŁA², KATARZYNA CIESIELCZYK²,
ZBIGNIEW SZYGUŁA³, PIOTR J. THOR²

THE CHANGES OF HEART RATE VARIABILITY IN RESPONSE TO DEEP BREATHING IN PROFESSIONAL SWIMMERS

Abstract: Introduction: The analysis of heart rate variability (HRV) is a useful tool for the evaluation of adaptation processes of autonomic nervous system (ANS) to physical exercise. The deep breathing test (DB) induces the increased activity of the parasympathetic component of ANS. The aim of the study was to evaluate the influence of DB on ANS activity in professional swimmers and non-trained persons.

Methods: The study included 10 healthy swimmers (5 women and 5 men, mean age 21 ± 2 yrs) in the transitory phase of their training cycle, and a control group comprising 31 healthy volunteers. The evaluation of ANS activity was based on the time and frequency domain indices of HRV determined at rest and during DB.

Results: Compared to the controls, swimmers were characterized by significantly higher values of the following HRV indices determined at rest: mRR (902.9 ± 102.5 ms vs. 744 ± 67.5 ms, $p < 0.05$), rMSSD (71.4 ± 46.9 ms vs. 41.3 ± 20.7 ms, $p < 0.05$), pNN50 ($28.3 \pm 17.4\%$ vs. $14 \pm 10.7\%$, $p < 0.05$), LF (603.5 ± 208.2 ms² vs. 445.2 ± 137 ms², $p < 0.03$). Also during DB test, the values of the following HRV indices of the swimmers were significantly higher than in the controls: mRR (899.2 ± 69.2 ms vs. 766.4 ± 63.6 ms, $p < 0.05$), SDNN (114.1 ± 45.1 ms vs. 79 ± 27.7 ms, $p < 0.05$), rMSDD (81.9 ± 38.2 ms vs. 50.7 ± 27 ms, $p < 0.05$), pNN50 ($32.9 \pm 14.3\%$ vs. $20.6 \pm 14.6\%$, $p < 0.05$), TP (1972.7 ± 809.5 ms² vs. 1329.7 ± 532 ms², $p < 0.05$), HF (657.1 ± 330.9 ms² vs. 405.7 ± 217 ms², $p < 0.05$), LF (753.3 ± 294 ms² vs. 533 ± 213.4 ms², $p < 0.05$). The analysis of value relative DB-induced changes in time and frequency domain HRV indices revealed significant intergroup differences in reaction to parasympathetic stimulation.

Conclusions: Based on the results presented in this study, the swimmers' response to deep breathing seems stronger than in persons without professional training. The deep breathing test may be a useful tool to evaluate the dynamic changes in the parasympathetic activity of ANS of sportspersons.

Key words: autonomic nervous system, physical exercise, heart rate variability, deep breathing test, swimmers.

INTRODUCTION

Measurement of heart rate variability (HRV) is a non-invasive technique that can be used to investigate the function of the autonomic nervous system (ANS), especially the balance between sympathetic and vagal activity [1]. Detailed analysis

of short-term fluctuations in instantaneous heart period has been widely used to indirectly assess ANS regulation of cardiovascular function. Sympathetic impulses increase heart rate by exciting the sinoatrial (SA) node while parasympathetic impulses reduce heart rate by inhibiting it. Time and frequency analysis of heart rate could be a valuable tool to investigate the adaptation mechanisms of cardiovascular regulation used in response to exercise [2].

The deep breathing (DB) is a reliable and highly sensitive measure of cardiovascular or parasympathetic cardiac function. The high-frequency cardiac rhythms are mediated primarily by vagal innervation of the SA reflecting the respiratory sinus arrhythmia (RSA) characterized by increased heart rate during inspiration followed by its decrease during expiration. Adults in excellent cardiovascular health, such as endurance runners, swimmers, and cyclists, are likely to have more pronounced RSA [3, 4].

Swimming is a very demanding sport, and being able to breathe efficiently is vital for practicing this discipline. It is important to maintain a steady and rhythmic inhale-exhale pattern and maximize air intake without compromising the stroke. Proper breathing techniques during swimming require practice, and the ability to hold one's breath under water during dolphin kick helps increase the speed in competitive swimming [5, 6]. Therefore, exercises stimulating the respiratory system constitute a considerable percentage of the training time in swimmers.

Regular physical training promotes the synchronization between heart rate and respiratory frequency. Taking into account the functional variability of the vegetative system, it can be supposed that the changes in heart rate variability will be more diversified in swimmers as compared to persons leading the average lifestyle. Differences in the reply to the stimulus of respiratory regularity, applied in the attempt of deep breathing, are also expected.

OBJECTIVE

The aim of this study was to investigate the influence of swimming training on the autonomic nervous system in healthy subjects and to analyze the effect of the deep breathing test on the activity of ANS manifested by HRV indices in professional swimmers and in individuals who did not practice sport.

MATERIAL AND METHODS

The study included 10 professional swimmers (experimental group), among them 5 women and 5 men, with the mean age of 21 ± 2 years (range 19–23 years) and training experience of 10 ± 3 years. The control group comprised individuals who neither currently nor previously practiced any sports discipline. These individuals

participated in 60-minute sessions of physical activity twice a week on average, either as a part of physical education classes included in their study curriculum or on their own. Thirty-one controls were examined, among them 9 women and 22 men, mean age 20 ± 1 years (range 19–21 years).

The inclusion criteria of the study included negative history of cardiovascular disorders, diabetes, and obesity, neurological disorders, using medications influencing the activity of ANS, other medications, and such stimulants as coffee, cigarettes, and caffeine-containing drinks. All participants had normal arterial blood pressure and heart rate and showed normal sinus rhythm on ECG.

The swimmers were examined once during the transitory phase of their training cycle (registration prior to the training — at rest). The examination took place at conditions promoting the comfort of the subjects: in a massage room, at 24°C, during the morning hours, and at least 12 hours after the last training session (in the case of swimmers).

After a 20-minute rest in a supine position, a 10-minute electrocardiogram (ECG) was recorded. Subsequently, each participant was asked to breathe deeply for 5 minutes, with a breathing frequency of 6 breaths/min (5 sec inspiration, 5 sec expiration; one full cycle every 10 seconds). During this time, continuous ECG was recorded [7].

Resting electrocardiograms and those obtained during the DB test were recorded with a three-channel digital recorder ASPEKT 700, which registers electrocardiographic signaling without compression on PCMCIA semiconductor memory cards. The measurements of arterial pressure were obtained with HOMEDICS MiBody 360 sphygmomanometer.

Prior to HRV analysis, fragments containing R-R intervals determined by sinus stimulation were selected. The R-R intervals representing the extra-sinus stimulation were excluded, as well as the artifacts that were mistakenly identified as stimulation by the analyzer. After the preparation of electrocardiograms, the variability of sinus rhythm was evaluated by means of temporal and spectral analysis at proper, predefined time periods. The analysis was conducted with HolCARD 24W software, version 5.11.00 (Aspel, Poland). The following components of the temporal analysis of HRV were determined: mRR — average R-R interval of the sinus rhythm; SDNN — standard deviation of the average R-R intervals of the sinus rhythm (in ms), a global index which describes the total variability of sinus rhythm; rMSSD — square root of the mean squared difference of successive R-R intervals (in ms), a measure which refers to the short-term variability and correlates with the high-frequency component of spectral analysis; pNN50 — proportion of successive R-R intervals that differ by more than 50 ms, expressed in %, which correlates significantly with rMSSD. Also the measures determined during the spectral analysis were studied: TP (Total Power), total spectral power at the whole range of frequencies (0.0033–0.15 Hz); LF (Low Frequency), low-frequency component (0.04–0.15 Hz), modulated by the sympathetic system, associated with

the cyclic changes of arterial pressure, and dependent upon baroreceptor activity; HF (High Frequency), high-frequency component (0.15–0.4 Hz), a variability modulated by the parasympathetic system, associated with breathing; LF/HF, low-frequency to high-frequency component ratio, defines mutual relationships of the components of vegetative modulation; and normalized values of the HRV spectral indices: NLF [LF/(TP-VLF)*100] and NHF [HF/(TP-VLF)*100].

The protocol of the study was approved by the Local Bioethical Committee of the Jagiellonian University (approval no. KBET/26/B/2012). All qualified individuals gave their informed written consent to participate in the study.

STATISTICAL ANALYSIS

Non-parametric tests for small samples were used. The differences between dependent variables were analyzed with the Wilcoxon test, while the differences between the experimental and the control group were tested with the non-parametric Mann-Whitney U test. The analysis was conducted with SPSS v. 17 software. The results were presented as arithmetic means and their standard deviations (SD). The level of statistical significance was set at $p < 0.05$.

RESULTS

RESTING ACTIVITY OF ANS IN PROFESSIONAL SWIMMERS AND IN THE CONTROLS

At rest, in supine position and without an imposed rhythm of respiration, swimmers showed significantly higher values of rMSSD, pNN50, LF, and HF than persons without physical training (Table 1). Furthermore, a longer average R-R interval of the sinus rhythm and lower heart rate were noted in the experimental group in comparison to the controls.

ANS RESPONSE TO DB IN PROFESSIONAL SWIMMERS AND IN THE CONTROLS

During DB, the values of all analyzed time and frequency domain indices of HRV, except the LF/HF ratio, were significantly higher in the swimmers than in the controls ($p = 0.127$, Table 2).

The analysis of relative DB-induced changes in time and frequency domain HRV indices (Fig. 1 and 2) revealed significant intergroup differences in reaction to parasympathetic stimulation. Compared to the controls, professional swimmers were characterized by relatively less pronounced changes in all analyzed time domain HRV indices (mRR, rMSSD, pNN50) except SDNN (Fig. 1). In the case of the frequency domain indices, the swimmers showed greater increase in TP and LF and less pronounced decrease in HF than the controls. These changes suggest

Table 1

Mean values of time and frequency domain HRV indices in professional swimmers and in the controls, determined at rest in supine position without an imposed rhythm of respiration. Mean — arithmetic mean, SD — standard deviation, mRR — average R-R interval of the sinus rhythm, SDNN — standard deviation of the average R-R intervals of the sinus rhythm, rMSSD — square root of the mean squared difference of successive R-R intervals, pNN50 — proportion of successive R-R intervals that differ by more than 50 ms, TP — total spectral power at the whole range of frequencies (0.0033–0.15 Hz), LF — low-frequency component (0.04–0.15 Hz), HF — high-frequency component (0.15–0.4 Hz), LF/HF — low-frequency to high-frequency component ratio.

Parameters	Experimental group (swimmers) (n = 10)		Control group (n = 31)		Mann-Whitney U test		Difference between groups (%)
	Mean	SD	Mean	SD	U	p	
mRR [ms]	902.90	102.50	744.09	67.51	31.50	0.000	21%
SDNN [ms]	94.80	54.71	68.00	24.40	103.50	0.119	39%
rMSSD [ms]	71.40	46.92	41.32	20.77	82.50	0.026	72%
pNN50 [%]	28.37	17.44	14.08	10.73	86.00	0.036	102%
TP [ms ²]	1942.00	909.17	1533.00	605.16	114.00	0.223	26%
HF [ms ²]	716.40	441.14	496.22	255.92	103.00	0.119	44%
LF [ms ²]	603.50	208.29	445.22	137.07	86.00	0.036	35%
LF/HF	0.96	0.28	1.03	0.35	150.50	0.893	-6%

Table 2

Mean values of time and frequency domain HRV indices in professional swimmers and in the controls, determined at rest in supine position during DB test. Mean — arithmetic mean, SD — standard deviation, mRR — average R-R interval of the sinus rhythm, SDNN — standard deviation of the average R-R intervals of the sinus rhythm, rMSSD — square root of the mean squared difference of successive R-R intervals, pNN50 — proportion of successive R-R intervals that differ by more than 50 ms, TP — total spectral power at the whole range of frequencies (0.0033–0.15 Hz), LF — low-frequency component (0.04–0.15 Hz), HF — high-frequency component (0.15–0.4 Hz), LF/HF — low-frequency to high-frequency component ratio.

Parameters	Experimental group (swimmers) (n = 10)		Control group (n = 31)		Mann-Whitney U test		Difference between groups (%)
	Mean	SD	Mean	SD	U	p	
mRR [ms]	899.20	69.28	766.45	63.60	18.00	0.000	17%
SDNN [ms]	114.10	45.12	79.03	27.70	80.50	0.022	44%
rMSSD [ms]	81.90	38.21	50.74	27.08	75.50	0.014	61%
pNN50 [%]	32.99	14.31	20.60	14.63	81.00	0.024	59%
TP [ms ²]	1972.70	809.51	1329.74	532.02	74.50	0.013	48%
HF [ms ²]	657.10	330.95	405.74	217.06	81.00	0.024	62%
LF [ms ²]	753.30	294.07	533.00	213.45	81.00	0.024	41%
LF/HF	1.30	0.59	1.47	0.47	104.00	0.127	-7%

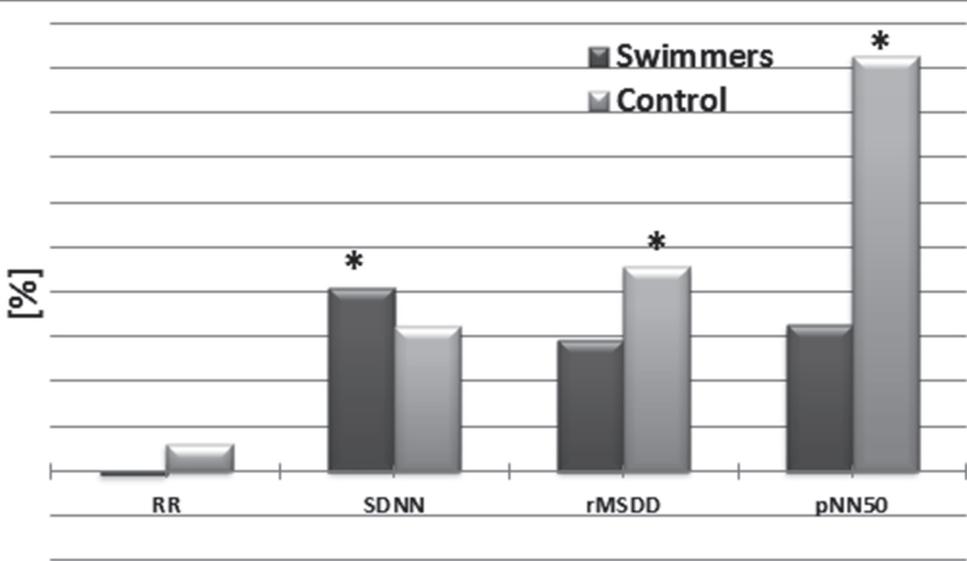


Fig. 1. Relative change in the time domain indices of HRV documented in response to parasympathetic stimulation during DB in swimmers and in the controls. * — significant differences, $p < 0.05$. mRR — average R-R interval of the sinus rhythm, SDNN — standard deviation of the average R-R intervals of the sinus rhythm, rMSSD — square root of the mean squared difference of successive R-R intervals, pNN50 — proportion of successive R-R intervals that differ by more than 50 ms.

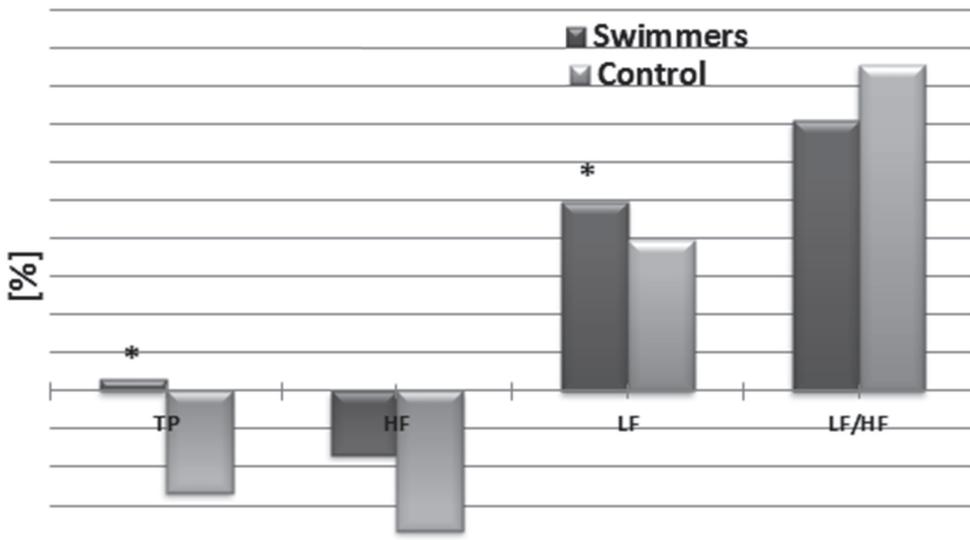


Fig. 2. Relative change in the frequency domain indices of HRV documented in response to parasympathetic stimulation during DB in swimmers and in the controls. * — significant differences, $p < 0.05$. TP — total spectral power at the whole range of frequencies (0.0033–0.15 Hz), LF — low-frequency component (0.04–0.15 Hz), HF — high-frequency component (0.15–0.4 Hz), LF/HF — low-frequency to high-frequency component ratio.

that despite the dominance of parasympathetic component of ANS observed at rest, the athletes showed stronger response to DB than individuals who neither currently nor previously practiced any sports discipline.

DISCUSSION

Physical activity modulates the cardiovascular system; this is reflected by a gradual withdrawal of vagal cardiac tone, along with a gradual increase in sympathetic cardiac and vasomotor tone. These autonomic modulations are initiated through both central commands from the somatic motor cortex and muscle chemoreceptive and mechanoreceptive inputs. Additionally, there is an upward resetting of the operating point of the arterial baroreflex, with preserved reflex sensitivity. This resetting is directly associated with the intensity of the exercise from rest to maximal workloads. Previous studies of ECG monitoring revealed that compared to their healthy subjects of similar age and body posture but sedentary lifestyle, athletes are characterized by significantly longer R-R intervals and significantly higher values of HRV indices: SDNN, pNN50 and rMSSD [8, 9]. Our study documented similar profile of differences in resting HRV indices of swimmers and sedentary controls. Probably, these differences resulted from different arterial baroreceptor reflex sensitivity in these two groups [10]. According to literature, this is cardiopulmonary baroreflex which plays vital role in the control of heart filling [11]. Recently Mack *et al.* revealed that similar to arterial baroreceptors, also the sensitivity of the cardiopulmonary baroreceptors is changed in response to exercise [12].

Our findings documented at rest, without DB, are consistent with the results of previous research. Compared to the controls, our swimmers were characterized by longer R-R interval and higher values of rMSSD and pNN50 indices. Consequently, we revealed that compared to individuals characterized by moderate levels of physical activity, swimmers show an increase in the parasympathetic and a decrease in the sympathetic modulation. Similar results were previously reported by Carter, in the longitudinal study of adult runners [13].

Our study revealed that individuals who practiced swimming showed significantly higher values of low frequency component (LF) as compared to the controls. Literature data on the differences in LF of trained and non-trained persons are inconclusive. Melanson documented similar values of frequency analysis components (HF and LF) as in our study [14]. The values of LF at rest correspond to both sympathetic and parasympathetic modulation. Higher values of HRV in the swimmers point to its greater variability associated with the parasympathetic dominance [1].

The changes in heart rate variability were more pronounced during deep breathing test. Both in the athletes and in the controls, the stimulation associated with enforced breath rate during the DB test was reflected by a similar direction

of changes in indices characterizing the response of ANS to this factor [15]. An increase in LF and LF/HF ratio was observed, along with a decrease in HF, which points to correct response to this type of stimulation [16, 17]. The swimmers showed significantly higher values of all HRV indices except the LF/HF ratio. The swimmers' values of mRR, rMSSD, pNN50 and LF were higher at rest as well, and the implementation of DB further increased the level of statistical significance. These relationships suggest that the parasympathetic activity in swimmers is higher than in their moderately active peers.

The response to the DB revealed significant intergroup differences in reaction to parasympathetic stimulation. The professional swimmers, in comparison to the controls, were characterized by relatively less pronounced changes in all analyzed time domain HRV indices (mRR, rMSSD, pNN50) except SDNN (a global index describing the total variability of sinus rhythm). In the case of the frequency domain indices, the swimmers showed greater increase in TP and LF and less pronounced decrease in HF than the controls. These changes suggest that despite the dominance of the parasympathetic component of ANS observed at rest, the athletes showed stronger response to DB than individuals who neither currently nor previously practiced any sports discipline. Therefore, it can be concluded that the breathing stimulation used in this study exerts a significantly greater effect on the neural regulation of heart rhythm in athletes than in the controls. None of the previous studies compared the response to DB in swimmers and non-trained individuals.

Both our findings and literature data suggest that physical training is reflected by greater heart rhythm variability [2, 18, 19], and trained individuals are characterized by greater variability of sinus rhythm than non-trained persons not only at rest but also in response to ANS stimulation. This was confirmed by the swimmers' response to the parasympathetic stimulation of ANS during deep breathing which was significantly stronger than in the controls. Probably, this reflected the hemodynamic phenomenon described by Hansen *et al.* [20], referred to as functional sympatholysis. These authors revealed that an increase in muscle sympathetic nervous activity (MSNA) during exercise is not reflected by vascular stenosis. This phenomenon was confirmed in cats by Komine *et al.* [21], and results in the parasympathetic dominance [22].

In conclusion, the DB test used in our study is an important direct method of assessing the effect of ANS on heart rhythm in swimmers. Our findings confirmed the hypothesis that heart rhythm variability increases in response of physical training, as both the values of time and frequency domain indices of trained individuals were higher than in non-trained persons.

Determination of HRV seems to be a potentially important tool for monitoring athletes' adaptation to physical exercise, and could be used both during the process of training and for educational purposes. Consequently, the issues addressed in this paper require further studies.

CONCLUSION

Our study revealed that the DB test constitutes a strong activator of parasympathetic nervous system, both in athletes and non-trained persons. The DB test used in our study seems proper for indirect assessment of the dynamics of changes in ANS of professional athletes and individuals who do not practice any sports discipline and are characterized by moderate levels of physical activity.

ACKNOWLEDGMENT

The study was supported by grant number K/ZDS/002963 (specific subsidy for holding the research capacity of the Ministry of Science and Higher Education).

CONFLICT OF INTEREST

None declared.

REFERENCES

1. Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology: Heart rate variability. Standards of measurement, physiological interpretation and clinical use. *Circulation*. 1996; 93: 1043–1065. — 2. *Szmitgielska K., Jegier A.*: Zmienność rytmu zatokowego serca a wysiłek fizyczny. *Medicina Sportiva*. 2004; 8 (Suppl. 2): 17–26. — 3. *Hirsch J.A., Bishop B.*: Respiratory sinus arrhythmia in humans: how breathing pattern modulates heart rate. *Am J Physiol*. 1981; 241: 620–629. — 4. *May O., Arildsen H., Moller M.*: Parasympathetic function during deep breathing in the general population: relation to coronary risk factors and normal range. *J Intern Med*. 1999; 245: 287–294. — 5. *Hellard P., Guimaraes F., Avalos M. Houel N., Hausswirth C., Toussaint J.F.*: Modeling the association between HR variability and illness in elite swimmers. *Med Sci Sports Exerc*. 2011; 43(6): 1063–1070. — 6. *Schaal K., Le Meur Y., Bieuzen F., Petit O., Hellard P., Toussaint J.F., Hausswirth C.*: Effect of recovery mode on postexercise vagal reactivation in elite synchronized swimmers. *Appl Physiol Nutr Metab*. 2013; 38(2): 126–133. — 7. *Zygmunt A., Stanczyk J.*: Methods of autonomic nervous system function. *Arch Med Sci*. 2010; 6(1): 11–18. — 8. *Melanson E.L.*: Resting heart rate variability in men varying in habitual physical activity. *Med Sci Sports Exerc*. 2000; 32: 1894–1901. — 9. *Kobuszevska-Chwirot M., Raczak G., Toruński A.*: Wpływ długotrwałego, intensywnego treningu fizycznego na czynność autonomicznego układu nerwowego u wyczynowych sportowców. *Folia Cardiol*. 2004; 11(10): 765–770. — 10. *McIveen S.A., Hayes S.G., Kaufman M.P.*: Both central command and exercise pressor reflex reset carotid sinus baroreflex. *Am J Physiol Heart Circ Physiol*. 2001; 280: 1454–1463.
11. *Fadel P.J., Raven P.B.*: Human Investigations into the Arterial and Cardiopulmonary Baroreflexes during Exercise. *Exp Physiol*. 2012; 97(1): 39–50. — 12. *Mack G., Nose H., Nadel E.R.*: Role of cardiopulmonary baroreflexes during dynamic exercise. *J Appl Physiol*. 1988; 65: 1827–1832. — 13. *Carter J.B., Banister E.W., Blaber A.P.*: The effect of age and gender on heart rate variability after endurance training. *Med. Sci. Sports Exerc*. 2003; 35(8): 1333–1340. — 14. *Melanson E.L.*: Resting heart rate variability in men varying in habitual physical activity. *Med. Sci. Sports Exerc*. 2000; 32: 1894–1901. — 15. *Furgala A., Mazur M., Kolasieńska-Kloch W., Thor P.J.*: Wpływ pobudzenia nerwu błędnego przez głębokie oddychanie i rzekome karmienie na odpowiedź układu autono-

- micznego u kobiet. *Folia Medica Cracov.* 2008; 49(3–4): 59–66. — **16.** *Elghozi J.L., Laude D., Girard A.*: Effects of respiration on blood pressure and heart rate variability in humans, *Clin Exp Pharmacol Physiol.* 1991; 18: 735–742. — **17.** *Aysin B., Aysin E.*: Effect of respiration in heart rate variability (HRV) analysis. *Conf Proc IEEE Eng Med Biol Soc.* 2006; 1: 1776–1779. — **18.** *Nummela A.*: Zmienność rytmu serca w nocy podczas przygotowań do wyścigów mistrzowskich w dyscyplinach wytrzymałościowych. Materiały Konferencyjne „Tapering and Peeking before main event” Akademia Trenerska, Warszawa 19–20.11.2011. — **19.** *Palak K., Furgala A., Biel P., Szygula Z., Thor P.J.*: Influence of physical training on the function of autonomic nervous system in professional swimmers. *Medicina Sportiva*, 2013; 17(3): 119–124. — **20.** *Hansen J., Thomas G.D., Harris S.A., Parsons W.J., Victor R.G.*: Differential sympathetic neural control of oxygenation in resting and exercising human skeletal muscle. *J Clin Invest.* 1996; 98: 584–596.
- 21.** *Komine H., Matsukawa K., Tsuchimochi H., Murata J.*: Central command blunts the baroreflex bradycardia to aortic nerve stimulation at the onset of voluntary static exercise in cats. *Am J Physiol Heart Circ Physiol.* 2003; 285: 516–526. — **22.** *Gilbey M.P.*: Sympathetic rhythms and nervous integration. *Clin Exp Pharmacol Physiol.* 2007, 34: 356–361.

¹ Educational Center
for Physical Education and Sport
AGH University of Science and Technology
in Cracow, Poland

² Department of Pathophysiology
Jagiellonian University Medical College,
Kraków, Poland

³ Department of Sports Medicine
and Human Nutrition
University School of Physical Education
in Cracow, Poland

Author for correspondence:

Klaudia Palak MSc
Educational Center for Physical Education and Sport
AGH University of Science and Technology in Cracow
ul. Piastowska 26a, 30-070 Kraków, Poland
Phone: +48 600 951 938
E-mail: klaudiapalak@o2.pl