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Cardio-respiratory endurance of individuals with different blood pressure levels

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Abstract. Evaluation of cardio-respiratory endurance in individuals with different levels of blood pressure is one of the key factors in preventing the development of diseases of the cardiovascular system. The purpose of the study was to conduct a comparative assessment of cardio-respiratory endurance, the level of maximum oxygen consumption, and the results of the Ruffier test in individuals with different blood pressure levels. 320 people were examined, of which 4 groups were formed according to the initial level of blood pressure. After measuring baseline blood pressure and heart rate, all subjects underwent a Ruffier test (30 sit-ups for 45 seconds), followed by repeated heart rate measurements at 15 seconds, 1 minute, and blood pressure measurements at 3 minutes. Determination of the level of maximum oxygen consumption was performed according to the formula. Representatives of the group with normal-low and normal blood pressure have a significantly higher level of maximum oxygen consumption. Individuals with normal-high blood pressure and first-degree hypertension had higher levels of systolic and diastolic blood pressure during daily blood pressure monitoring, both during the day and at night, compared to individuals with normal and normal-low blood pressure. It was established that people with normal-low blood pressure have a higher cardio-respiratory endurance than people with normal-high blood pressure and first-degree hypertension. The findings of the study can be used by cardiologists and general practitioners for early detection and prevention of diseases of the cardiovascular system, and physiologists in further investigation of the features of the functioning of the cardiovascular system

Keywords: Ruffier test; daily blood pressure monitoring; cardio-respiratory endurance; maximum oxygen consumption

INTRODUCTION

Prevention of the development of diseases of the cardiovascular system is an important task of modern medicine. The key step in solving this problem is to examine the features of the functioning of the cardiovascular system. One of the main indicators for this is cardio-respiratory endurance (CRE).

CRE, according to the interpretation of J. Myers *et al.* [1], is a complex indicator of the state of the body, used for early diagnosis of hypertension, coronary heart disease, and other chronic diseases. P.F. Kokkinos *et al.* [2] and M.P. Harber *et al.* [3] observed the association between CRE levels and the body's respiratory function, metabolic activity, physical activity, and anthropometric parameters. B. Mitskan *et al.* [4] confirm that individuals with low CRE levels during physical exertion develop a violation of bioenergetic processes in peripheral blood red blood cells, a decrease in the production of adenosine triphosphate (ATP), and an increase in the content of intra-erythrocyte 2.3-diphosphoglycerate (DPG). R. Ortega *et al.* [5] note that reduced CRE is also a factor in the occurrence of dys-

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lipidemia, which, in turn, contributes to the further development of cardiovascular diseases.

A simple and well-known CRE test is the Ruffier test, which analyses the dynamics of heart rate in response to physical activity. N. Kotsur & L. Tovkun [6] found that lower-than-average Ruffier test results in adolescents aged 14-16 years were associated with reduced functional reserves of the cardiovascular system. Y. Guo *et al.* [7] and G. Papini *et al.* [8] suggest that the Ruffier test with a high level of reliability allows determining the maximum level of oxygen consumption, beyond which there is no further increase in oxygen consumption with increasing load intensity (VO_{2max}).

L. Jay & X.L. Zhang [9] found that VO_{2max} it is a reliable method for estimating CRE, as it reflects the integrated ability to transport oxygen from the atmosphere to the mitochondria to perform physical work, and it quantifies the functional capacity of the human body.

A.D. Hughes & N. Chaturvedi [10] established that between the level of blood pressure (BP) and VO_{2max} there is a significant negative correlation. The studies by P. Boutouyrie *et al.* [11] confirm that an increase in BP leads to an increase in arterial stiffness and a decrease in the ability to transport blood and oxygen to working muscles.

Daily blood pressure monitoring (DBPM) provides a more complete assessment of the state of the cardiovascular system and allows predicting the health consequences better than single BP measurements in the clinic or at home [12, 13]. W.Y. Yang *et al.* [14] determined that data from 24-hour DBPM and, in particular, night BP monitoring are valuable predictors of the development of hypertension complications and overall cardiovascular mortality. I.A. Plesh *et al.* [15] found that the progression of hypertension is associated with changes in the circadian rhythm of BP. Individuals with a low level of nocturnal BP dipping had a higher degree of left ventricular wall hypertrophy and an increased discrepancy between the left ventricular (LV) myocardial mass index and the LV myocardial mass, which indicates an acceleration in the progression of hypertension.

The purpose of this study was to establish the features of CRE, the results of the Ruffier test, and the level of maximum oxygen consumption in individuals with different BP levels.

MATERIALS AND METHODS

The study was conducted in August-November 2022 at the certified laboratory of psychophysiological research (Certificate No. 055/13) of the Department of Physiology with Basics of Bioethics and Biosafety at the I.Ya. Horbachevsky Ternopil National Medical University, Ministry of Health of Ukraine.

The study involved 240 individuals aged 18-22 years without cardiovascular diseases and not taking antihypertensive medications, and 80 individuals aged 18-22 years with stage 1 hypertension but not taking antihypertensive medications during the examination.

All participants underwent baseline BP measurements. The participants were divided into four groups of 80 individuals each based on their BP levels according to the recommendations of the European Society of Cardiology [16]: Group I – individuals with optimal or normal-low baseline BP (< 120/80 mmHg); Group II – individuals with normal BP (120/80-129/84 mmHg); Group III – individuals with normal-high BP (130/85-139/89 mmHg); Group IV – individuals with stage 1 hypertension (BP: 140/90-159/95 mmHg).

After measuring BP, a Ruffier test was performed. Before the test, the subjects rested for 5 minutes in a supine position. Then, the initial heart rate (HR) was determined in the standing position. After that, the subjects performed 30 squats for 45 seconds. The squat rhythm was set by a metronome (80 beats per minute). Squats were performed by bending the knees to a 90° angle, with the participant keeping their back straight and arms extended forward. After the test, HR was measured again at 15 seconds and 1 minute intervals, and BP was measured after 3 minutes. The Ruffier-Dickson index was determined using the formula [9]:

$$Index = \frac{(HR2-70)+2\times(HR3-HR1)}{10}, \qquad (1)$$

where HR1 is in the initial state, HR2 is 15 seconds after the test, and HR3 is after 1 minute of rest. Heart rate is indicated in beats per minute.

VO_{2max} was determined with the formula [8]:

$$VO_{2max} = 3{,}0143 + 1{,}1585\times Gender - 0{,}0268\times \times\left(\frac{HR1}{Height}\right) + 118{,}761\times \left[\frac{(HR2-HR3)}{Age^3}\right., \qquad (2)$$

where gender is encoded: 1 for men and 0 for women, HR1 – in the initial state, HR2 – 15 seconds after the test, HR3 – after 1 minute of rest. Heart rate is indicated in beats per minute, age in full years, and height in metres.

All subjects underwent daily pressure monitoring using the ABPpro device. The frequency of measurements was every 30 minutes during the day (from 08:00 to 22:00) and every hour during the night (from 22:00 to 08:00). The level of nocturnal decrease in systolic BP (%) was calculated using the formula:

$$\frac{daytime\ systolic\ BP - nighttime\ systolic\ BP}{daytime\ systolic\ BP}\times 100. \qquad (3)$$

The obtained results were statistically processed using the open-source statistical package "R" [17]. The normality of the distribution of groups was assessed using the Shapiro-Wilk test. The homogeneity of variances between independent groups was determined using Levene's test. One-way analysis of variance (ANOVA) was used to assess the significance of the effects of the studied factors. The statistical significance of the differences between groups was determined using Tukey's post hoc test and Student's t-test.

Throughout the study, adherence to bioethical norms, such as the Helsinki Declaration and the World Medical Association's "Ethical Principles for Medical Research Involving Human Subjects", was ensured [18]. All subjects, before participating in the experiment, gave written informed consent to conduct the study. Confidentiality of personal data of the subjects was ensured.

RESULTS

The average values of systolic BP were as follows: Group I – 107 ± 4.93 mmHg, Group II – 125 ± 2.34 mmHg, Group III – 136 ± 2.24 mmHg, and Group IV – 145 ± 2.81 mmHg. After the Ruffier test, the systolic BP values were: Group I –

127 ± 5.38 mmHg, Group II – 143 ± 3.41 mmHg, Group III – 159 ± 3.54 mmHg, and Group IV – 173 ± 3.68 mmHg.

All groups showed a significant ($p < 0.05$) increase in systolic BP after the Ruffier test compared to baseline (Fig. 1).

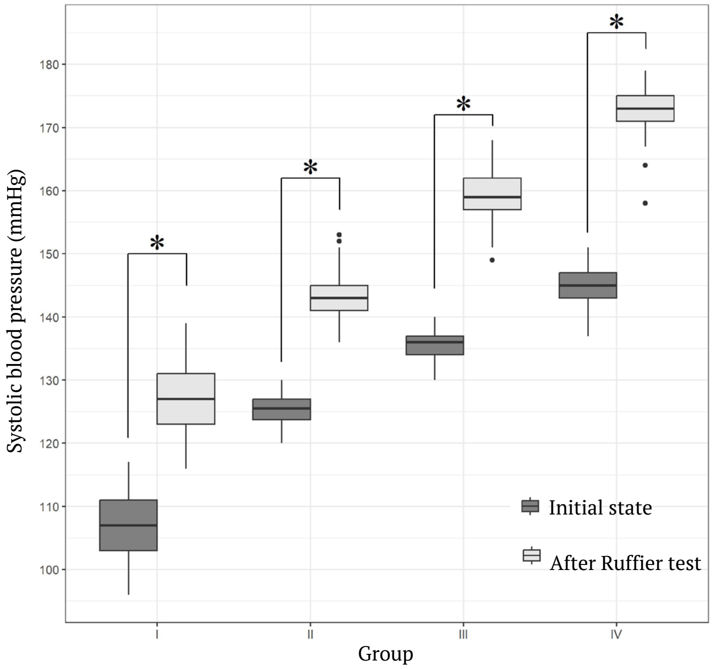

Figure 1. Dynamics of systolic BP after physical exercise
Notes: * – significantly different from the baseline value ($p < 0.05$)
Source: compiled by the authors

The increase in systolic blood pressure after physical exercise was 20.0 ± 2.46 mmHg (18.7% of the baseline value) in Group I, 17.8 ± 2.69 mmHg (14.24%) in Group II, 23.9 ± 2.40 mmHg (17.6%) in Group III, and 28.1 ± 2.15 mmHg (19.38%) in Group IV. Significantly higher increases in systolic blood pressure after physical exercise were observed in participants from Group III and Group IV compared to those from Group I and Group II (Fig. 2).

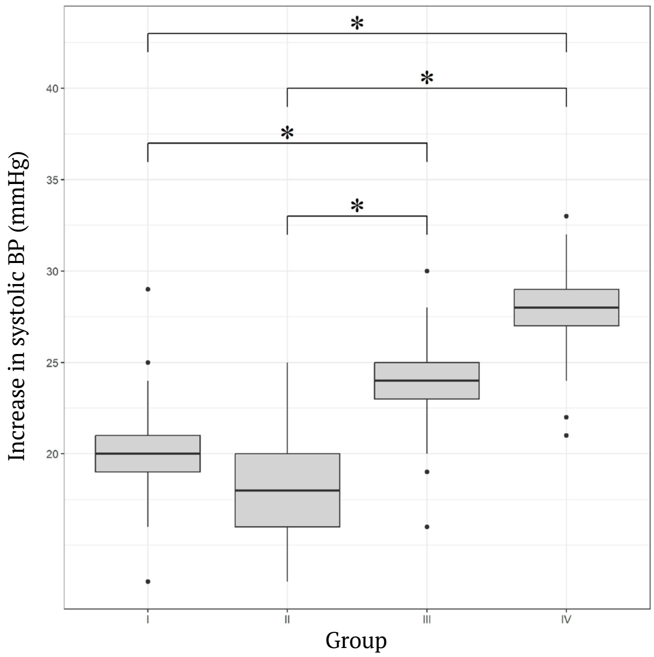

Figure 2. Increase in systolic BP after physical exercise
Notes: * – significantly different from Group I and Group II ($p < 0.05$)
Source: compiled by the authors

The average values of diastolic BP were as follows: Group I – 69.4 ± 2.17 mmHg, Group II – 79.4 ± 3.58 mmHg, Group III – 90 ± 3.43 mmHg, and Group IV – 96 ± 2.23 mmHg. After the Ruffier test, the diastolic BP values were: Group I – 79.1 ± 2.90 mmHg, Group II – 88.5 ± 4.71 mmHg, Group III – 102±3.92 mmHg, and Group IV – 109±2.96 mmHg. In all groups, a significant ($p < 0.05$) increase in diastolic BP was observed after the Ruffier test compared to the baseline level (Fig. 3).

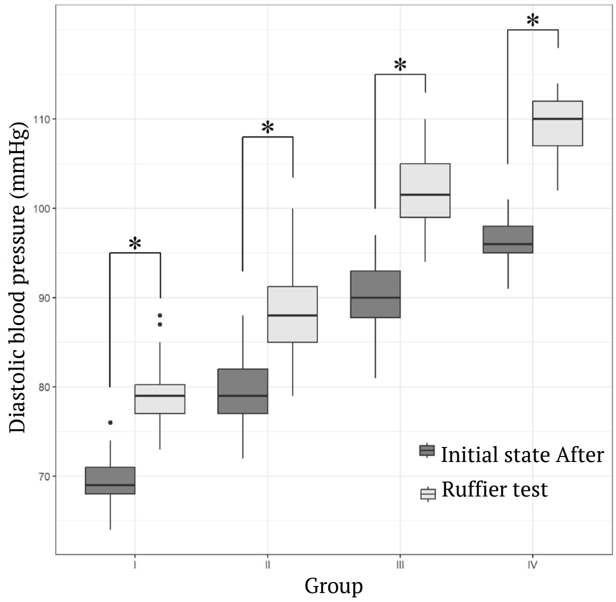

Figure 3. Dynamics of diastolic BP after physical exercise
Notes: * – significantly different from the baseline value ($p < 0.05$)
Source: compiled by the authors

The increase in diastolic blood pressure after physical exercise was 9.69 ± 2.26 mmHg (13.96% of the baseline value) in Group I, 9.05 ± 2.47 mmHg (11.4%) in Group II, 11.6 ± 2.26 mmHg (12.88%) in Group III, and 13.4 ± 2.30 mmHg (13.95%) in Group IV. Significantly higher increases in diastolic blood pressure after physical exercise were observed in participants from Group III and Group IV compared to those from Group I and Group II (Fig. 4).

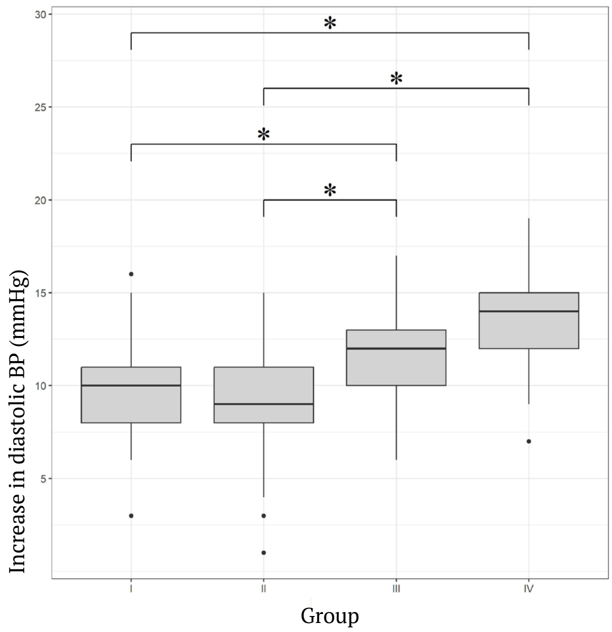

Figure 4. Increase in diastolic BP after physical exercise
Notes: * – significantly different from Group I and Group II ($p < 0.05$)
Source: compiled by the authors

The increase in HR after the Ruffier test indicates an intensified sympathetic influence on cardiac activity, as evidenced by the increase in HR at 15 seconds and 1 minute after exercise (Table 1).

Table 1. Heart rate dynamics after physical exercise

Group	Initial state, min-1	After 15 seconds, min-1	After 1 minute, min-1
I	71.8 ± 7.74	126 ± 7.90*	87.9 ± 7.87
II	70.4 ± 7.11	123 ± 7.28*	83.3 ± 7.43
III	75.4 ± 7.65	137 ± 7.55*	108 ± 7.54**, ***
IV	80.1 ± 724	145 ± 7.42*	117 ± 7.61**, ***

Notes: * – significantly different from the baseline value ($p < 0.05$). ** – Significantly different from Group I ($p < 0.05$). *** – Significantly different from Group II ($p < 0.05$)
Source: compiled by the authors

At 15 seconds after physical exercise, HR increased by 54.0 ± 0.961 beats/min^{-1} (75.2%) in Group I, 52.2 ± 1.08 beats/min^{-1} (74.14%) in Group II, 62.0 ± 0.948 beats/min^{-1} (82.23%) in Group III, and 65.4 ± 0.995 beats/min^{-1} (81.16%) in Group IV. Participants from Group III and Group IV had a significantly ($p < 0.05$) higher increase in HR at 15 seconds after exercise compared to those from Group I and Group II. 1 minute after physical activity, the increase in HR from the initial value in the subjects of Group I was 16.1 ± 2.15 min^{-1} (22.42%), Group II – 12.9 ± 1.92 min^{-1} (18.32%), Group III – 32.4 ± 2.35 (42.9%), Group IV – 36.5 ± 2.15 (45.56%). Participants from Group III and Group IV had a significantly ($p < 0.05$) higher increase in HR at 1 minute after exercise compared to those from Group I and Group II.

These findings indicate that individuals in Group III and Group IV had a significantly higher HR at 1 minute after the Ruffier test, indicating a more pronounced cardiovascular response to sympathetic influences in these groups. The significantly higher level of the Rufier-Dixon index in participants from Group III and Group IV indicates their lower endurance to physical exercise (Table 2).

Table 2. Ruffier test results and maximum oxygen consumption level

Group	Ruffier-Dixon Index	Maximum oxygen consumption level (VO_{2max}), l / min	Maximum oxygen consumption level (VO_{2max}), ml / kg / min
I	8.80 ± 0.881	2.94 ± 0.638	43.9 ± 8.63
II	7.83 ± 0.847*	3.00 ± 0.637	44.5 ± 8.24
III	13.2 ± 0.831*, **	2.79 ± 0.593	40.5 ± 6.52*, **
IV	14.8 ± 0.893*, **	2.71 ± 0.640**	39.4 ± 7.75*, **

Notes: * – significantly different from Group I ($p < 0.05$). ** – Significantly different from Group II ($p < 0.05$)
Source: compiled by the authors

Vo_{2max} level in participants from Group I and Group II corresponds to a sufficient level of CRE (42-45 ml/kg/min). In representatives of groups III and IV, this indicator was significantly lower and equal to a low level of CRE (< 42 ml/kg/min).

During 24-hour ambulatory BP monitoring, the average systolic BP levels throughout the day were as follows: Group I – 109 ± 5.33 mmHg, Group II – 129 ± 3.93 mmHg, Group III – 140 ± 4.24 mmHg, and Group IV – 152 ± 4.13 mmHg. During the night, the systolic BP values were: Group I – 96.9 ± 5.38 mmHg, Group II – 116 ± 3.42 mmHg, Group III – 129 ± 3.17 mmHg, and Group IV – 139 ± 3.59 mmHg. DBPM showed a significantly higher BP in individuals of groups III and IV compared to I and II (Fig. 5).

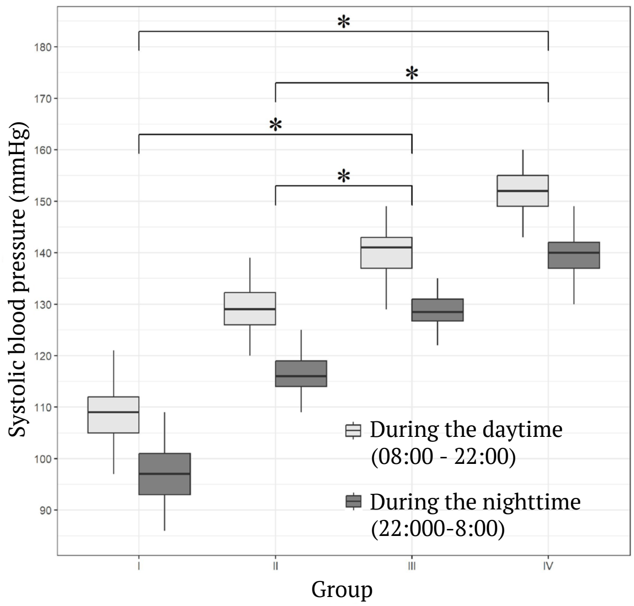

Figure 5. Daily monitoring of systolic BP
Notes: * – significantly different from Group I and Group II ($p < 0.05$)
Source: compiled by the authors

The diastolic BP during the daytime was: Group I – 70.0 ± 3.78 mmHg, Group II – 80.9 ± 5.17 mmHg, Group III – 93.0 ± 5.26 mmHg, and Group IV – 99.5 ± 3.93 mmHg. During the night, the diastolic BP values were: Group I – 60.8 ± 2.98 mmHg, Group II – 71.6 ± 4.37 mmHg, Group III – 83.6 ± 4.13 mmHg, and Group IV – 90.0 ± 3.26 mmHg. The level of diastolic BP during both daytime and nighttime was significantly higher in individuals from Group III and Group IV compared to those from Group I and II (Fig. 6).

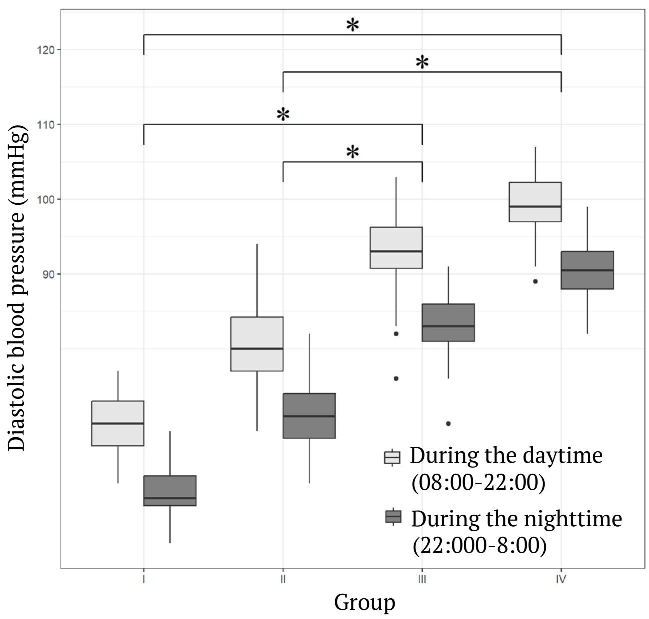

Figure 6. Daily monitoring of diastolic BP
Notes: * – significantly different from Group I and Group II ($p < 0.05$)
Source: compiled by the authors

Participants from Group III with a normal-high baseline BP level and Group IV with first-degree hypertension had significantly higher 24-hour BP values compared to individuals with normal-low BP (Group II) and individuals with normal BP (Group III). The level of nocturnal BP dipping, expressed as the percentage reduction in systolic BP, was 10.6 ± 3.38% in Group I, 9.99 ± 2.97% in Group II, 8.2 ± 2.82% in Group III, and 8.14 ± 2.81% in Group IV (Fig. 7).

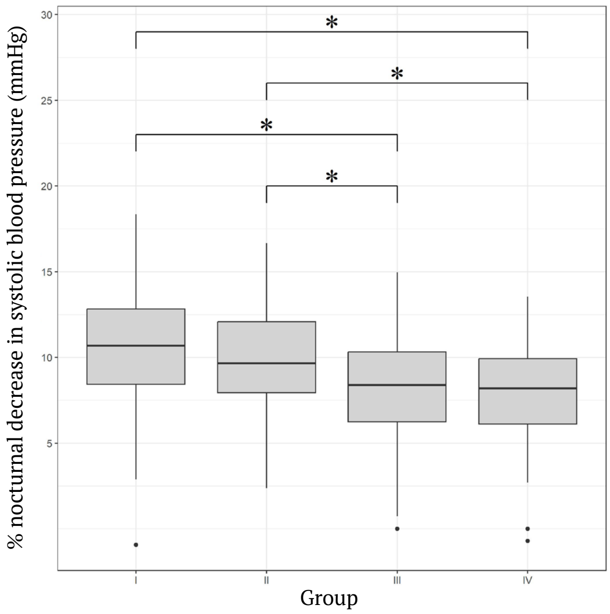

Figure 7. The level of nocturnal decrease in systolic BP

Notes: * – significantly different from Group I and Group II ($p < 0.05$)

Source: compiled by the authors

A significantly lower level of nocturnal decrease in systolic BP was established in individuals I and II Groups in comparison with representatives of III and IV Groups ($p < 0.05$).

DISCUSSION

The study revealed an increase in both systolic and diastolic BP after physical exertion in all groups of participants. A greater degree of increase in systolic and diastolic BP was observed in individuals with normal-high BP and hypertension. These results can be explained by more pronounced sympathetic responses to physical exertion in individuals with normal-high BP and hypertension. E.N. Bardsley & D.J. Paterson [19] confirm that increased sympathetic tone is an important factor in the development of hypertension. A key role in this process is played by genetically determined imbalances between intracellular levels of cyclic adenosine monophosphate (cAMP) and cyclic guanosine monophosphate (cGMP), leading to an increase in intracellular Ca2+ levels and activation of the sympathetic system cascade. This disruption in BP regulation leads to its elevation, increased risk of arrhythmias, and cardiomyopathies.

The results of the study indicate that individuals with normal-high BP and hypertension have lower levels of VO_{2max}. Additionally, these groups showed higher HR values at the 1-minute mark after physical exertion. The findings are consistent with study by K.A. Alahmari *et al*. [20], which demonstrated a strong negative correlation between BP levels and VO_{2max}, and between heart rate and VO_{2max}. One possible physiological mechanism underlying these changes is increased vascular resistance due to increased vascular wall stiffness in individuals with normal-high BP and hypertension. This leads to impaired transportation of oxygenated blood to the muscles during physical exertion. J. Mahdiabadi [21] established a correlation between a 10.3 ml/kg/min increase in VO_{2max} and a decrease in systolic BP by 10.2 mmHg and diastolic BP by 5.9 mmHg.

In a retrospective study, T. Holmlund *et al*. [22] found that negative CRE dynamics are associated with an increased risk of pre-hypertension and hypertension. Thus, individuals who had an annual decrease in CRE from -1.0% to -2.9% had a 21% higher risk of hypertension, and individuals with an annual decrease in CRE ⩾-3% had a 25% higher risk of hypertension. Moreover, individuals with an increase in CRE by ⩾+3% had an 11% lower risk of hypertension.

In a meta-analysis of the relationship between CRE and hypertension conducted by C. Cheng *et al.* [23] concluded that the risk of hypertension was 37% lower in people with high CRE compared to people with low CRE, and 15% lower in people with moderate CRE compared to people with low CRE. In addition, in the cohort study by J. Lee *et al*. [24], involving 2 962 subjects, individuals with high CRE during 9 years of follow-up had a 29% lower risk of coronary heart disease, a 25% lower risk of acute myocardial infarction, a 46% lower risk of stroke, and a 44% lower risk of overall mortality compared to individuals with low CRE. The observed patterns are confirmed in this study, as it was found that individuals with normal to low and normal BP had higher levels of maximal oxygen consumption and, consequently, higher CRE compared to individuals with normal to high BP and hypertension.

In this study, the mean values of systolic and diastolic BP, when monitored daily, were higher both during the day and during the night in individuals with normal-high BP and hypertension compared to individuals with normal BP and normal-low BP. Furthermore, the level of nocturnal decrease in systolic BP was higher in subjects with normal-low and normal BP levels compared to people with normal-high and high BP. The results obtained are consistent with the conclusions of the EXERDIET-HTA study conducted by I. Gorostegi-Anduaga *et al*. [25], which established that individuals with low CRE have significantly lower levels of nocturnal BP dipping compared to individuals with moderate to high CRE.

Considering the data of the scientific literature and the results of this study, it can be argued that individuals with normal to high BP and those with stage 1 hypertension experience changes in the functioning of the cardiovascular system, reflected in lower CRE and a reduced nocturnal BP dipping, which in turn is evidence of a risk of further progression of arterial hypertension and the development of other cardiovascular diseases.

CONCLUSIONS

Individuals with normal-high BP and first-degree hypertension are characterised by a lower level of maximum oxygen consumption during physical exertion than individuals with normal-low BP. The lower level of endurance of the cardiovascular system to physical activity in those examined with normal-high BP and hypertension of the first degree is indicated by a lower level of the Ruffier-Dixon index in them, compared with those examined with normal-low BP and normal BP.

During daily BP monitoring, individuals with normal-high BP and first-degree hypertension had significantly higher levels of systolic and diastolic BP both during the day and at night compared to individuals with normal and normal-low BP. The level of nocturnal BP dipping was lower in subjects with normal-high BP and first-degree hypertension.

The results obtained can be used in the practice of cardiologists and family physicians for early diagnosis and prevention of hypertension, and in the work of physiologists to examine the features of the functioning of the cardiovascular system.

For further studies, a detailed analysis of fluctuations in daily BP in different groups of subjects and the development of prognostic models for clinical application of the results obtained is promising.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Кардіо-респіраторна витривалість осіб із різним рівнем артеріального тиску

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Анотація. Оцінка кардіо-респіраторної витривалості в осіб із різним рівнем артеріального тиску є одним із ключових факторів попередження розвитку захворювань серцево-судинної системи. Мета роботи полягала у проведенні порівняльної оцінки кардіо-респіраторної витривалості, рівня максимального споживання кисню та результатів проби Руф'є в осіб із різним рівнем артеріального тиску. Обстежено 320 осіб, із яких сформовано 4 групи згідно вихідного рівня артеріального тиску. Усім обстежуваним після вимірювання вихідного артеріального тиску та частоти серцевих скорочень проведено пробу Руф'є (30 присідань протягом 45 секунд), після чого виконано повторне вимірювання частоти серцевих скорочень через 15 секунд, 1 хвилину та вимірювання артеріального тиску через 3 хвилини. Визначення рівня максимального споживання кисню проводилося згідно формули. Представники групи із нормально-низьким та нормальним артеріальним тиском мають достовірно більший рівень максимального споживання кисню. У осіб із нормально-високим артеріальним тиском та гіпертонічною хворобою першого ступеня протягом добового моніторування артеріального тиску виявлено більший рівень систолічного та діастолічного артеріального тиску як в денний, так і в нічний період порівняно із особами із нормальним та нормально-низьким рівнем артеріального тиску. Проаналізовано, що особи із нормально-низьким артеріальним тиском мають більшу кардіо-респіраторну витривалість, ніж особи із нормально-високим артеріальним тиском та гіпертонічною хворобою першого ступеня. Результати роботи можуть бути використані лікарями кардіологами та лікарями загальної практики з метою раннього виявлення та попередження захворювань серцево-судинної системи, а також фізіологами при подальшому вивченні особливостей функціонування серцево-судинної системи

Ключові слова: проба Руф'є; добовий моніторинг артеріального тиску; кардіо-респіраторна витривалість; максимальне споживання кисню