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HYPERTENSION PREVALENCE IN YOUNG ADULTS ENGAGED IN DIFFERENT TYPES OF SPORTS

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Abstract
High blood pressure is one of the most significant risk factors for cardiovascular diseases. Although it is less common among active populations, athletes are not immune to hypertension, and its prevalence may vary depending on the type of sport. The research problem is evaluation of blood pressure parameters in 100 physically active young adults of both sexes, aged 19 to 25, involved in various sports characterized by differing types and load intensities (low, moderate, and/or high static, i.e. dynamic component), as well as comparison of these parameters' values between men (N=47) and women (N=53). Basic characteristics, such as age, body height, body mass, body mass index, body surface area, resting heart rate, and length of sports experience, were established, along with blood pressure parameters (systolic blood pressure – SBP, diastolic blood pressure – DBP, and mean arterial pressure – MAP). Data analysis, performed using SPSS 26.0, included descriptive statistics, the Kolmogorov-Smirnov test, the Mann-Whitney U test, the t-test, and the Chi-square test. Findings showed that, on average, men had isolated systolic hypertension (SBP>130 mmHg), with normal DBP and normal MAP values, while women showed normotensive values (SBP<120 mmHg and DBP<80 mmHg) and optimal MAP. The comparison of athletes engaged in different types of sports revealed noticeable differences (p=0.051) only in SBP values between female participants from Groups 1 (high dynamic and moderate static components) and 2 (high dynamic and low static components). Sex differences were significant overall, with exceptions only in DBP values between Groups 1 and 2. The Chi-square test revealed statistically significant relationship between sex and blood pressure (p<0.00001).

Keywords: ATHLETES / BLOOD PRESSURE / LOAD INTENSITY / SEX DIFFERENCES

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Online first

INTRODUCTION

Cardiovascular diseases are the leading cause of death in most developed and many developing countries, stemming from numerous risk factors such as obesity, high blood pressure, insufficient physical activity, hyperlipoproteinemia, poor nutrition, and unhealthy lifestyle choices (Wildman, Gu, Reynolds, Duan, Wu, & He, 2005). These diseases not only lead to significant disability but also drive-up healthcare costs (Stojanović, Višnjić, Mitrović, & Stojanović, 2009), and they are considered a "pediatric" problem (Rowland, 2007). This indicates that many risk factors present in youth tend to persist or even intensify into old age, particularly after the second or third decade of life (Stojanović et al., 2009). As a result, young individuals within at-risk groups often remain at risk throughout life, underscoring the importance of early identification and prevention. High blood pressure, i.e. hypertension, is one of the most critical risk factors for cardiovascular diseases and is the leading cause of mortality globally, accounting for approximately 10.7 million deaths per year (Niu, Duan, Yu, Xue, Liu, Yu et al., 2023). This chronic condition affects over a billion adults worldwide (Lamirault, Artifoni, Daniel, & Barber-Chamoux, 2019), and is characterized by elevated arterial blood pressure in the systemic circulation (systolic and/or diastolic blood pressure), which may result in functional or structural damage to the heart, brain, kidneys, and other organs (Niu et al., 2023). The incidence of high blood pressure continues to rise annually in most countries, with lifestyle factors playing a crucial role in this trend, including obesity, physical inactivity, inadequate diets, and detrimental lifestyle habits (Irazusta, Hoyos, Irazusta, Ruiz, Díaz, & Gil, 2007). Each of these factors has varying significance across populations, with physical inactivity alone believed to contribute to 5–13% of current cases of hypertension (Börjesson, Kjeldsen, & Dahlöf, 2010).

The aging of the human population and the increasing prevalence of chronic diseases underscore the link between physical activity and health. In everyday life, physical activity plays an important role in maintaining and enhancing health, provided it follows guidelines regarding both the nature and the intensity and frequency of physical exertion required (Stănescu & Vasile, 2014). As a result, intentional physical activity has become an essential element of a healthy lifestyle. Regular physical exercise is widely recognized for its significant role in preventing cardiovascular diseases by reducing their incidence and severity (Piepoli, Hoes, Agewall, Albus, Brotons, Catapano et al., 2016) and by lessening the prevalence and impact of related risk factors (D'Ascenzi, Caselli, Alvino, Digiacinto, Lemme, Piepoli, & Pelliccia, 2019). Consequently, athletes are often considered to have a low-risk health profile due to their age and consistent participation in exercise programs, instinctively viewed as models of a healthy lifestyle. However, while high blood pressure is less frequent in active populations, athletes are not immune to hypertension. Studies indicate that hypertension prevalence may vary across sports and, notably, may be even higher among competitive athletes than the general population (Schweiger, Niederseer, Schmied, Attenhofer-Jost, & Caselli, 2021).

Therefore, the attention traditionally focused on the health of the elderly must also extend to younger populations, including those who exercise regularly, lead healthy lifestyles, and may not outwardly display risk factors (Purenović-Ivanović, Stojanović, Veličković, Živković, & Đošić, 2022). This shift is essential for the early recognition and prevention of cardiovascular diseases, aiming to reduce their prevalence and mitigate their impact. The importance of detecting elevated blood pressure in young people is growing, which is why this research focuses on the blood pressure values in young adult athletes of both sexes. The research problem is the evaluation of blood pressure parameters (systolic and diastolic blood pressure, and mean arterial pressure) in physically active young adults of both sexes participating in various sports, considering the type and load intensity (low, moderate, and/or high static, i.e. dynamic component) (Mitchell, Haskell, Snell, & Van Camp, 2005), as well as comparison of these values in men and women.

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METHODS

Study participants

For this study, the sample was drawn from university student athletes. A total of 100 participants (M=47, W=53), aged between 19 and 25, were included, all of whom had voluntarily agreed to participate. The participants were organized into three subgroups based on the type and intensity of physical demands associated with their respective sports (classification according to Mitchell et al., 2005): Group 1 (N=36, i.e. 36%: M=16, W=20) – participants involved in sports characterized by moderate static and high dynamic components (e.g., basketball, handball, swimming, middle-distance running) or by high static and moderate dynamic components (e.g., bodybuilding, wrestling, snowboarding); Group 2 (N=41, i.e. 41%: M=22, W=19) – participants engaged in sports with high static and low dynamic components (e.g., throwing events in athletics, gymnastics, certain martial arts, weightlifting), sports with moderate levels of both static and dynamic component (e.g., American football, jumping events in athletics, sprinting, synchronized swimming), or sports with low static and high dynamic components (e.g., soccer, long-distance running, tennis); Group 3 (N=23, i.e. 23%: M=9, W=14) – participants practicing sports with moderate static and low dynamic components (e.g., equestrian, motor sports) or with low static and moderate dynamic components (e.g., volleyball, table tennis).

Measures and procedures

The study protocol received approval from the local ethics committee (No. 04-336/2). Testing was conducted in alignment with the ethical standards of the Declaration of Helsinki (WMA, 2013) by the same examiner, during morning hours, in a well-lit room with optimal climate conditions. All participants were minimally dressed, rested, and in good health, and measurement results were recorded by an assistant on data sheets prepared specifically for this research. Participants provided information about their age (Age, in years), the type of sport they engage in, and the length of their sports experience (SPEXP, in years) through interviews. Anthropometric measurements were conducted according to the methods outlined by Eston, Hawes, Martin, & Reilly (2009) and Martin's anthropometer was used to measure participants' body height (Height, in 0.1 cm). Body mass (Weight, in 0.1 kg) and body mass index (BMI, in 0.1 kg/m^2) were assessed using a bioimpedance device – Omron BF511 (Kyoto, Japan), following input of the participant's age, sex, and body height. Body surface area (BSA, in 0.1 m^2) was calculated using Mosteller's formula: $BSA\ (m^2) = \sqrt{[Weight\ (kg) \times Height\ (cm) / 3600]}$ (Mosteller, 1987). Using an Omron HEM-9200T digital blood pressure monitor, resting heart rate (RHR, in bpm), systolic blood pressure (SBP, in mmHg), and diastolic blood pressure (DBP, in mmHg) were recorded. Mean arterial pressure (MAP, in 0.1 mmHg) was then calculated using the formula: $MAP = 1/3 \times SBP + 2/3 \times DBP$ (Ma, Li, Sheng, Quan, Yang, Xu, & Zeng, 2023).

Statistical data analysis

Data analysis was conducted using the Statistical Package for the Social Sciences, version 26.0 (IBM SPSS 26.0, SPSS Inc, Chicago, USA). At the univariate level, the basic descriptive statistics of all variables were calculated: average value (Mean), standard deviation (SD), minimum (Min), and maximum (Max). The Kolmogorov-Smirnov (K-S) test was used to assess the normality of variable distribution. To evaluate statistical significance for differences in blood pressure parameters among male, i.e. female study participants involved in various sports, as well as for comparing men and women, the Mann-Whitney U test and the t-test were used. The Chi-square test (χ^2) was applied to determine the statistical significance of the relationship between sex and blood pressure. A 95% confidence level, i.e. $p<0.05$, was set as the criterion for statistical significance.

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RESULTS

Baseline characteristics of the study participants

Table 1 Baseline characteristics of the male study participants (N=47)

Variables	M	Group 1 (n=16)	Group 2 (n=22)	Group 3 (n=9)	Total (N=47)
Age (yrs)	*Mean±SD*	19.90±1.56	19.89±1.48	20.07±1.91	19.93±1.56
	Min – Max	18.94 – 25.47	18.78 – 24.25	19.07 – 25.12	18.78 – 25.47
Height (cm)	*Mean±SD*	180.39±10.11	177.89±6.97	181.54±3.26	179.41±7.74
	Min – Max	169.5 – 208.5	160.7 – 193.0	176.3 – 185.0	160.7 – 208.5
Weight (kg)	*Mean±SD*	81.32±11.17	76.06±10.50	73.40±9.19	77.37±10.72
	Min – Max	66.0 – 98.7	54.9 – 98.0	57.2 – 85.4	54.9 – 98.7
BMI (kg/m²)	*Mean±SD*	24.92±3.14	23.98±2.48	22.24±2.54	23.98±2.83
	Min – Max	20.4 – 30.8	18.7 – 29.4	18.4 – 26.1	18.4 – 30.8
BSA (m²)	*Mean±SD*	2.02±0.17	1.94±0.16	1.92±0.13	1.96±0.16
	Min – Max	1.78 – 2.27	1.62 – 2.23	1.67 – 2.07	1.62 – 2.27
RHR (bpm)	*Mean±SD*	72.56±11.60	74.27±14.59	74.22±15.01	73.68±13.45
	Min – Max	50 – 87	56 – 110	53 – 102	50 – 110
SPEXP (yrs)	*Mean±SD*	6.53±2.89	11.09±4.28	6.00±5.02	8.56±4.61
	Min – Max	0.5 – 11	3 – 19	0.5 – 15	0.5 – 19

Legend: n, N– number of study participants, **M–** men, **Mean–** average value, **SD–** standard deviation, **Min–** minimum, **Max–** maximum, **yrs–** years, **bpm–** beats per minute, **Height–** body height, **Weight–** body mass, **BMI–** body mass index, **BSA–** body surface area, **RHR–** resting heart rate, **SPEXP–** length of sports experience.

Table 2 Baseline characteristics of the female study participants (N=53)

Variables	W	Group 1 (n=20)	Group 2 (n=19)	Group 3 (n=14)	Total (N=53)
Age (yrs)	*Mean±SD*	21.28±1.43	21.38±1.62	20.67±1.27	21.15±1.46
	Min – Max	18.92 – 24.10	18.97 – 24.97	18.7 – 21.96	18.7 – 24.97
Height (cm)	*Mean±SD*	166.46±6.35	163.99±5.93	165.14±6.85	165.23±6.31
	Min – Max	157.0 – 182.4	153.0 – 175.0	156.5 – 179.0	153.0 – 182.4
Weight (kg)	*Mean±SD*	62.93±7.76	63.81±10.49	60.49±7.27	62.6±8.67
	Min – Max	51.1 – 82.2	46.2 – 88.4	46.0 – 74.1	46.0 – 88.4
BMI (kg/m²)	*Mean±SD*	22.74±2.75	23.74±3.42	22.14±2.40	22.94±2.94
	Min – Max	19.5 – 30.2	18.4 – 32.5	18.8 – 28.1	18.4 – 32.5
BSA (m²)	*Mean±SD*	1.70±0.12	1.70±0.16	1.66±0.12	1.69±0.13
	Min – Max	1.52 – 1.94	1.43 – 2.01	1.41 – 1.88	1.41 – 2.01
RHR (bpm)	*Mean±SD*	83.5±14.52	79.63±13.86	74.64±7.08	79.77±12.98
	Min – Max	63 – 123	59 – 107	63 – 84	59 – 123
SPEXP (yrs)	*Mean±SD*	8.13±3.94	8.47±3.08	7.86±3.54	8.18±3.49
	Min – Max	1 – 15	3 – 15	0.5 – 13	0.5 – 15

Legend: n, N– number of study participants, **W–** women, **Mean–** average value, **SD–** standard deviation, **Min–** minimum, **Max–** maximum, **yrs–** years, **bpm–** beats per minute, **Height–** body height, **Weight–** body mass, **BMI–** body mass index, **BSA–** body surface area, **RHR–** resting heart rate, **SPEXP–** length of sports experience.

Tables 1 and 2 present the basic descriptive parameters for the baseline characteristics of the male and female sample groups, respectively, with each subsample (group) displayed separately. According to the adult

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BMI classification scale (Ross & Janssen, 2007), the majority of respondents (30 men, i.e. 63.83%; 44 women, i.e. 83.02%) were of normal weight; 14 men (29.78%) and 6 women (11.32%) were pre-obese; two men (4.26%) and only one woman (1.89%) were underweight, and class I obesity was observed in one man (2.13%) and two women (3.77%). In the present sample of student athletes, the highest BSA was observed in Group 1 (2.02 m²) for male participants (Table 1) and in Groups 1 and 2 (1.70 m²) for female participants (Table 2), which are sports with moderate to high static and/or dynamic components. When it comes to resting heart rate, most participants exhibited normal RHR values (24 men, i.e. 51.06%; 30 women, i.e. 56.6%), followed by elevated RHR (14 men, i.e. 29.79%; 18 women, i.e. 33.96%). Regarding extremes, bradycardia was more common in men (7 men, i.e. 14.89%; 1 woman, i.e. 1.89%), while tachycardia was more frequent in women (2 men, i.e. 4.26%; 4 women, i.e. 7.55%). Examining each subsample, both male and female athletes generally showed normal heart rates (60<RHR<80 bpm), though female athletes' rates were closer to the upper end of the normal range (79.77±12.98 bpm). Notably, female athletes in Group 1 recorded an elevated average RHR (83.5±14.52 bpm).

The Mann-Whitney *U* test (analysis results not shown in tables) indicated no statistically significant differences across all baseline characteristics between subsamples participating in different types of sports (Group 1 vs. Group 2 vs. Group 3: p>0.05), except for the length of sports experience among male participants (Group 1 vs. Group 2: U=69.000, p=0.001; Group 2 vs. Group 3: U=43.500, p=0.015) and for RHR among female participants involved in sports with widely varying static and dynamic components' intensities (Group 1 vs. Group 3: U=78.500, p=0.031).

Blood pressure values of the study participants

In the sample of physically active young adults, male student athletes (top half of Table 3) exhibited high systolic blood pressure values (SBP>130 mmHg) across each group individually and within the subsample as a whole, indicating stage 1 hypertension based on elevated SBP alone. Unlike SBP, DBP in male student athletes was below 80 mmHg, indicating normal DBP values. However, MAP values were within the normal range (93.33<MAP<99.00 mmHg), suggesting that, based on MAP, the male participants do not present with hypertension. In contrast, the female student athletes (bottom half of Table 3) exhibited normotensive values on average (SBP<120 mmHg and DBP<80 mmHg), as well as optimal mean arterial pressure (MAP<93.33 mmHg), both individually within each group and in the overall subsample.

Table 3 Blood pressure values in male (M) and female (W) study participants

Variables	M	Group 1 (n=16)	Group 2 (n=22)	Group 3 (n=9)	Total (N=47)
SBP (mmHg)	*Mean±SD*	135.75±10.67	132.77±16.15	130.22±7.51	133.29±13.04
	Min – Max	114.0 – 152.0	98.0 – 160.0	117.0 – 141.0	98.0 – 160.0
	K-S (Sig.)	.645	.818	.973	.557
DBP (mmHg)	*Mean±SD*	77.0±7.31	79.73±9.20	77.89±7.96	78.45±8.29
	Min – Max	66.0 – 93.0	61.0 – 100.0	60.0 – 88.0	60.0 – 100.0
	K-S (Sig.)	.903	.269	.858	.213
MAP (mmHg)	*Mean±SD*	96.58±7.30	96.08±14.10	95.33±7.39	96.11±10.86
	Min – Max	83.33 – 109.33	54.33 – 120.0	79.0 – 105.67	54.33 – 120.0
	K-S (Sig.)	.992	.759	.839	.301
Variables	**W**	**Group 1 (n=20)**	**Group 2 (n=19)**	**Group 3 (n=14)**	**Total (N=53)**
SBP (mmHg)	*Mean±SD*	111.20±8.22	117.21±11.21	112.36±10.77	113.66±10.23
	Min – Max	99.0 – 125.0	91.0 – 143.0	100.0 – 141.0	91.0 – 143.0
	K-S (Sig.)	.576	.766	.826	.690

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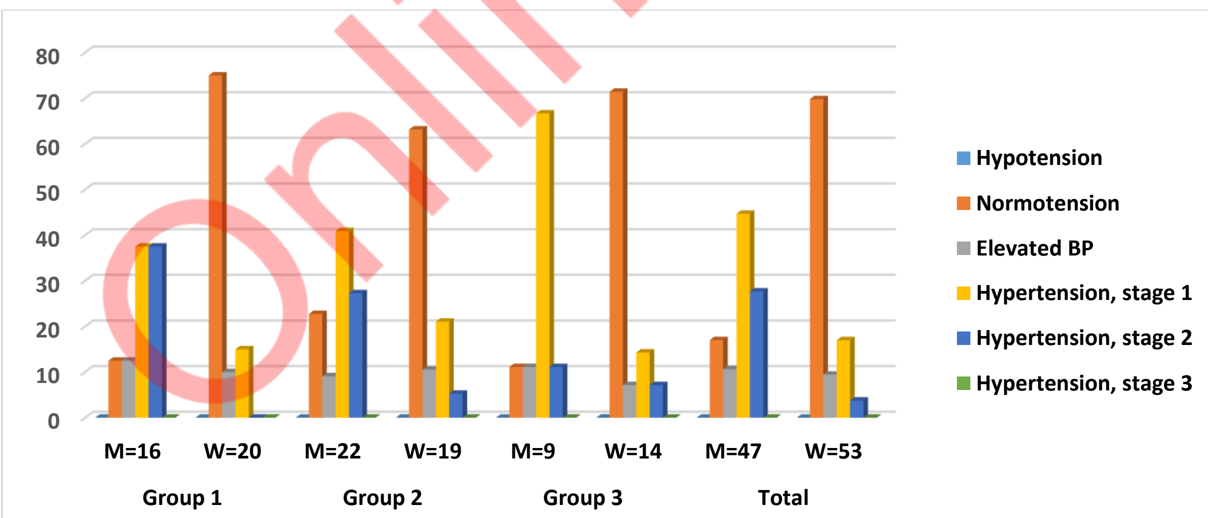
DBP (mmHg)	*Mean±SD*	72.20±6.51	74.79±8.18	70.86±8.34	72.77±7.66
	Min – Max	61.0 – 86.0	61.0 – 92.0	58.0 – 89.0	58.0 – 92.0
	K-S (Sig.)	.987	.969	.994	.533
MAP (mmHg)	*Mean±SD*	85.20±6.15	88.93±8.45	84.48±8.03	86.35±7.65
	Min – Max	74.0 – 98.33	70.0 – 109.0	74.67 – 98.33	70.0 – 109.0
	K-S (Sig.)	.989	.677	.965	.847

Legend: n, N– number of study participants, **M**– men, **W**– women, **Mean**– average value, **SD**– standard deviation, **Min**– minimumт, **Max**– maximum, **K-S**– Kolmogorov-Smirnov test, **Sig.**– significance, **SBP**– systolic blood pressure, **DBP**– diastolic blood pressure, **MAP**– mean arterial pressure.

Histogram 1 illustrates the prevalence of different blood pressure categories, based on systolic and diastolic blood pressure values (Börjesson et al., 2010; AHA, 2018), among male and female participants involved in various sports types (three groups), as well as within the overall subsamples. Considering the blood pressure categories, the breakdown among male and female study participants across the three sports groups (Groups 1, 2, and 3, respectively) is as follows: no cases of hypotension (SBP<90 mmHg and DBP<60 mmHg) or stage 3 hypertension (SBP>180 mmHg and/or DBP>120 mmHg) were recorded in any subsample; normotension (SBP<120 mmHg and DBP<80 mmHg) is more prevalent in female athletes across all three groups (Group 1: 15W vs. 2M, Group 2: 12W vs. 5M, Group 3: 10W vs. 1M) and the sample in total [37W (69.81%) vs. 8M (17.02%)]; elevated blood pressure (120<SBP<129 mmHg and DBP<80 mmHg) is almost equally represented in both male and female participants [Group 1: M=2, W=2; Group 2: M=2, W=2; Group 3: M=1, W=1; Total sample: five men (10.64%) and five women (9.44%)]; stage 1 hypertension (130<SBP<139 mmHg or 80<DBP<89 mmHg) is more frequent among male participants [Group 1: 6M vs. 3W, Group 2: 9M vs. 4W, Group 3: 6M vs. 2W, Total sample: 21M (44.68%) and 9W (16.98%)]; the same trend is observed with stage 2 hypertension (SBP>140 mmHg or DBP>90 mmHg) [Group 1: 6M vs. 0W, Group 2: 6M vs. 1W, Group 3: 1M vs. 1W, Total sample: 13M (27.66%) vs. 2W (3.77%)].



Histogram 1 The prevalence of different blood pressure categories (based on SBP and DBP values) in male (M) and female (W) study participants engaged in different types of sports

Histogram 2 presents the prevalence of different blood pressure categories based on mean arterial pressure values (Kandil, Soliman, Alghamdi, Jennings, & El-Baz, 2023) for male and female participants involved in different types of sports (three groups), as well as in the overall subsamples. According to this classification, a slightly different distribution is observed: optimal MAP values (MAP<93.33 mmHg) dominate across all three

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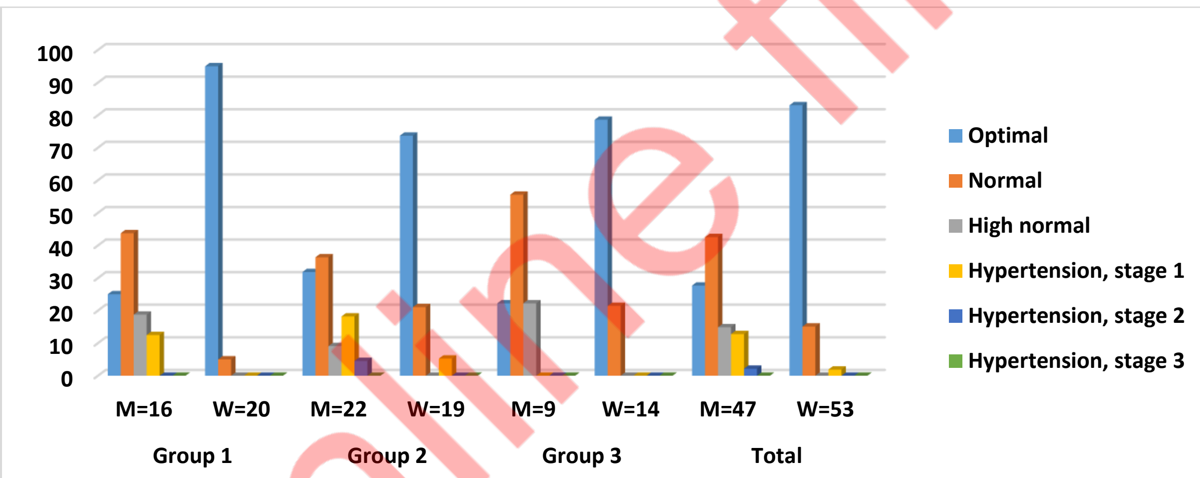
groups of female athletes (Group 1: 19W vs. 4M, Group 2: 14W vs. 7M, Group 3: 11W vs. 2M), and in the total sample [44W (83.02%) vs. 13M (27.66%)]; meanwhile, the normal MAP range (93.33<MAP<99.0 mmHg) is the most prominent blood pressure category among male participants (Group 1: 7M vs. 1W, Group 2: 8M vs. 4W, Group 3: 5M vs. 3W), and in the total sample [20M (42.55%) vs. 8W (15.09%)]; a high normal MAP value (99.01<MAP<105.67 mmHg) appeared only in the male sample (Group 1: N=3, Group 2: N=2, Group 3: N=2, Total sample: N=7, i.e. 14.89%); high MAP values, indicating stage 1 hypertension (105.68<MAP<119.0 mmHg), were absent in female Group 1 and Group 3 for both sexes [Group 1: 2M vs. 0W, Group 2: 4M vs. 1W, Total sample: 6M (12.77%) vs. 1W (1.89%)]; stage 2 hypertension (119.01<MAP<132.33 mmHg) was observed in only one male participant in Group 2, and stage 3 hypertension (MAP≥132.34 mmHg) was not found in any subsample, matching the classification based on systolic and diastolic blood pressure values. Interestingly, high blood pressure, i.e. hypertension, based on MAP value classification, was recorded in only one female participant (1.89%), whereas classification based on SBP and DBP indicated a much higher hypertension prevalence in female student athletes (N=11, i.e. 20.75%). A similar pattern emerged among male participants – based on MAP values, 14.89% (N=7) had hypertension, whereas over half of the male student athletes were categorized with hypertension (N=34, i.e. 72.34%) based on SBP and DBP values.



Histogram 2 The prevalence of different blood pressure categories (based on MAP values) in male (M) and female (W) study participants engaged in different types of sports

Reviewing both Histogram 1 and Histogram 2, along with Table 3, reveals that there are differences in blood pressure values among participants involved in different types of sports. However, these differences are not statistically significant, except for the SBP values of female study participants in Group 1 and Group 2 (U=120.500, p=0.051) – those respondents are engaged in sports with high dynamic components but varying static components, i.e. Group 1 involves a moderate static component, while Group 2 has a low static component. This finding aligns with previous research indicating that isometric (static) or resistance exercises increase peripheral vascular resistance (Leddy & Izzo, 2009), и and that such vascular modeling (Pescatello et al., 2004) leads to elevated blood pressure.

Sex differences in blood pressure are evident, with most reaching a statistically significant level (Table 4), except for diastolic blood pressure when comparing male and female participants in Groups 1 and 2. Additionally, the Chi-square test indicated a statistically significant relationship between sex and blood pressure values [$\chi^2(3,100)=32.431$, $p<0.00001$].

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Table 4 Sex differences in blood pressure values: Mann-Whitney *U* test and t-test [1]

Variables	Group 1 16M vs. 20W	Group 2 22M vs. 19W	Group 3 9M vs. 14W	Total 47M vs. 53W
SBP	U=14.000, **p=0.000**	U=85.000, **p=0.001**	U=11.000, **p=0.001**	t=8.425, **p=0.000**
DBP	U=102.000, p=0.064	U=148.000, p=0.110	U=30.500, p=0.040	t=3.558, **p=0.001**
MAP	U=35.000, **p=0.000**	U=113.000, p=0.012	U=23.000, p=0.012	t=5.240, **p=0.000**

Legend: M– men, **W**– women, **SBP**– systolic blood pressure, **DBP**– diastolic blood pressure, **MAP**– mean arterial pressure, **U**– contrast statistics, **t**– t test, **p**– level of statistical significance.

DISCUSSION

Baseline characteristics of the study participants

The study focused on young adults, though the age range for this group varies in the literature [16 to 25 years (Dovey-Pearce, Hurrell, May, Walker, & Doherty, 2005), 20 to 39 (Bleyer & Barr, 2009)]. Given these inconsistencies, it is reasonable to classify individuals aged 19 to 40 as young adults, based on Erik Erikson's developmental stages (Nelson, 2001; as cited in Tran & Zimmerman, 2015). This research targets young adults because they are at a life stage where they can make independent behavioral choices and establish habits that may affect their long-term cardiovascular risk, making them more suitable subjects than children, whose behaviors are primarily influenced by their guardians (Tran & Zimmerman, 2015).

Body mass index is the variable most frequently used to examine the relationship with blood pressure (Nardo, Chambless, Light, Rosamond, Sharrett, Tell, & Heiss, 1999). In a large-scale study (N=894,576), a nearly linear relationship was observed between BMI and blood pressure, showing an increase in SBP by approximately 5 mmHg and DBP by about 4 mmHg for every 5-unit (kg/m^2) increase in BMI (PSC, 2009). According to the adult BMI classification scale (Ross & Janssen, 2007), the majority of study respondents (M: 63.83%; W: 83.02%) were of normal weight, but there were some pre-obese (M: 29.78%; W: 11.32%) and even obese (class I obesity) among them (M: 2.13%; W: 3.77%). In previous research conducted a decade ago on Serbian student athletes (Moskovljević, 2013) and Croatian non-athlete students (Mašina, Zečić, & Pavlović, 2014; Selmanović, Čale-Mratović, & Ban, 2014), slightly lower BMI values were recorded, along with slightly higher average body height, in contrast to our study results. Regarding body mass, male participants from Serbia showed a slightly higher average value (78.21±6.01 kg), while in female students was a slightly lower (60.32±5.86 kg). However, a study on a U.S. sample of 5,101 non-athlete students (M=2,273, W=2,828) (Pribis, Burtnack, McKenzie, & Thayer, 2010) showed slightly higher BMI values in both male (24.1±4.5 kg/m^2) and female (24.0±5.3 kg/m^2) participants, likely due to sedentary lifestyles—a leading cause of increased student fat mass—as well as favorable socio-economic conditions (Subramanian, Perkins, Özaltin, & Davey Smith, 2011). Although BMI has clearly been shown to have an impact on blood pressure in case of very large sample of respondents (PSC, 2009), study of Evans, Wang, Greb, Kostas, Knapp, Zhang et al. (2017) demonstrated that in a smaller sample (N=34), BMI was less strongly correlated with blood pressure than with body mass, body height, or BSA. On average, the BSA values in this study (M: 1.96±0.16 m^2, W: 1.69±0.13 m^2) were slightly

[1] The results and significance of Levene's test are not shown in Table 4 (this refers only to the total sample), but they were taken into account, and based on the obtained significance for Levene's test, the corresponding row is shown (Equal variances assumed, i.e. the upper row, when the significance in this test is greater than 0.05 and Equal variances not assumed, i.e. the lower row, when the significance is less than 0.05).

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lower than those found in similar samples, though with slightly older participants (M: 2.0±0.3 m^2, W: 1.70±0.1 m^2; Evans et al., 2017; M: 1.99±0.21 m^2, W: 1.72±0.18 m^2; Caselli, Sequì, Lemme, Quattrini, Milan, D'Ascenzi et al., 2017). These values were also lower than those of elite athletes (M: 2.06±0.19 m^2 to 2.18±0.21 m^2; Mazic, Suzic Lazic, Dekleva, Antic, Soldatovic, Djelic et al., 2015), but higher compared to BSA values (1.92±0.21 m^2) reported by D'Ascenzi et al. (2018), likely due to the lack of sex separation in the sample of athletes.

Several epidemiological studies have established a strong association between RHR and SBP (Palatini, Dorigatti, Zaetta, Mormino, Mazzer, Bortolazzi et al., 2006; Palatini & Julius, 2009; Mazic et al., 2015). Elevated RHR is a significant risk factor for the development of hypertension in healthy individuals (Mazic et al., 2015) and is linked to a higher risk of adverse outcomes in patients with preexisting conditions, regardless of comorbidities or medical treatments (Palatini et al., 2006; Kolloch, Legler, Champion, Cooper-DeHoff, Handberg, Zhou, & Pepine, 2008). A lower heart rate is often associated with higher parasympathetic activity and is commonly observed in well-conditioned athletes (Lahiri, Kannankeril, & Goldberger, 2008). Athletes with high-normal and elevated blood pressure tend to have higher RHR, likely reflecting increased sympathetic activity and/or reduced parasympathetic tone (Mazic et al., 2015). This aligns with prior findings that elevated RHR, typical in hypertensive individuals, is also present in individuals with high-normal blood pressure (Palatini et al., 2006). In our study, most participants (M: 51.06%; W: 56.6%) exhibited normal RHR values, bradycardia was more common in men (M: 14.89%; W: 1.89%), while tachycardia was more frequent in women (M: 4.26%; W: 7.55%). Overall, these RHR values are higher than those reported in other studies on athletic populations, particularly among elite athletes (Mazic et al., 2015; Caselli et al., 2017; Obour, Moses, Baffour-Awuah, Asamoah, Sarpong, Osei et al., 2017; D'Ascenzi et al., 2019; Hedman, Moneghetti, Christle, Bagherzadeh, Amsallem, Ashley et al., 2019; Uzor, Uwa, & Ikwuka, 2024), suggesting that our student athletes are likely recreational rather than professional or elite athletes.

Blood pressure values of the study participants

Hypertension prevalence is on the rise globally, with expected increases in associated cardiovascular and cerebrovascular complications (Hanssen, Boardman, Deiseroth, Moholdt, Simonenko, Kränkel et al., 2022). Sustainable blood pressure management strategies are crucial, with regular physical activity and structured exercise being key components in prevention and treatment efforts. Although athletes are generally viewed as health and healthy lifestyle role models, hypertension is still prevalent among young people, including athletes (Hedman et al., 2019; Kim, Hollowed, Liu, Al-Badri, Alkhoder, Dommisse et al., 2019). Hypertension represents the most common cardiovascular condition in this population and is linked to reduced exercise capacity (Mazic et al., 2015), as well as adverse outcomes later in life (Yano, Reis, Colangelo, Shimbo, Viera, Allen et al., 2018). Compared to non-athletes, athletes show a lower prevalence of hypertension (De Matos, Caldeira, Perlingeiro, Dos Santos, Negrao, & Azevedo, 2011; Berge, Isern, & Berge, 2015), yet they possess unique risk factors, including intentional weight adjustments for specific sports, rigorous isometric training, use of supplements and stimulants, and, in some cases, the misuse of performance-enhancing substances (Tso & Kim, 2024). Berge et al. (2015) reported a prevalence of hypertension in athletes similar to that in sedentary populations, though blood pressure levels varied notably between athletes in different sports – strength sports, in particular, appear to be linked to higher blood pressure. Studies have shown that athletes in weightlifting, rowing, and American football exhibit higher blood pressure and are more likely to experience prehypertension or hypertension compared to endurance athletes (Williams, 2009; Schleich, Smoot, & Ernst, 2016; Kim, Zafonte, Pascuale-Leon, Nadler, Weisskopf, Speizer et al., 2018). Consequently, strength athletes do not benefit as endurance athletes do and may face higher cardiovascular risk (Runacres, Mackintosh, & McNarry, 2021). Aerobic exercise—characterized by rhythmic contractions of large muscle groups (e.g., running, walking, cycling, swimming, rowing)—elevates breathing rate and oxygen consumption (Pescatello, Franklin, Fagard,

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Farquhar, Kelley, & Ray, 2004), and it tends to increase heart rate and venous return (cardiac load). Conversely, resistance exercises like weightlifting increase peripheral vascular resistance and left ventricular afterload (Leddy & Izzo, 2009). In this way exercise impacts blood pressure through chronic effects on mechanisms of autonomic control and vascular remodeling (Pescatello et al., 2004). Thus, various factors related to sports—such as discipline, type, intensity, and even player position (Adamuz, 2016)—affect athlete's blood pressure. Several studies have shown that athletes generally experience reduced mortality, and longevity is inherent in those engaged in endurance sports (Garatachea, Santos-Lozano, Sanchis-Gomar, Fiuza-Luces, Pareja-Galeano, Emanuele, & Lucia, 2014; Schweiger et al., 2021) – common examples of endurance athletes include skiers and runners (Laukkanen, Kunutsor, Ozemek, Mäkikallio, Lee, Wisloff, & Lavie, 2019). Notably, the most significant reductions in blood pressure are observed at low to moderate exercise intensities.

In this study, the majority of male athletes, regardless of the type of sport, had elevated SBP and normal DBP. This condition, known as isolated systolic hypertension, is frequently observed in young people and is the most common form of hypertension among adolescents and adults (Bäckmand, Kujala, Sarna, & Kaprio, 2010; Laukkanen et al., 2019). Previously considered benign, a review study (McEniery, Cockcroft, Roman, Franklin, & Wilkinson, 2014) challenged this assumption, showing that individuals with isolated systolic hypertension often have greater discrepancies between brachial and central blood pressure, along with generally higher central blood pressure, which elevates the risk of persistent hypertension later in life. However, this same sample of male respondents, based on the value of mean arterial pressure, does not have hypertension, but rather normotension. When it comes to female respondents, they had normotensive values on average, as well as an optimal mean arterial pressure. This outcome aligns with expectations, as young women are generally known to have lower blood pressure (Joyner, Wallin, & Charkoudian, 2016). Also, given that acceptable blood pressure thresholds have been adjusted multiple times over the last 30 years (from 1997 to the present), which might have led to a notable increase in the prevalence of elevated blood pressure among young people, including athletes, it may be worthwhile to examine this issue more thoroughly. Consideration should be given to interpreting and classifying blood pressure using MAP values rather than solely relying on SBP and DBP values.

The observed sex differences in blood pressure (Table 4) are unsurprising, given existing evidence that androgenic hormones, such as testosterone, significantly influence sex-based differences in blood pressure regulation. Namely, ambulatory blood pressure monitoring in children have shown that blood pressure rises with age in both boys and girls (Reckelhoff, 2001). However, after entering a puberty, boys have higher blood pressure than girls of the same age, and these differences persist into adulthood, with men generally having higher blood pressure than their female peers, at least before menopause (Reckelhoff, 2001; Syme, Abrahamowicz, Leonard, Perron, Richer, Veillette et al., 2009; Радовановић & Стоичков, 2023). Aging impacts blood pressure differently in men and women, with the trend reversing after the eighth decade of life (Wiinberg, Høegholm, Christensen, Bang, Mikkelsen, Nielsen et al., 1995). Specifically, young women tend to have lower blood pressure and more frequent "hypotensive events" or disturbances, likely due to a reduced ability of their vascular sympathetic nerves to induce vasoconstriction. As women age, their blood pressure gradually aligns with that of men, and after menopause—in the seventh and eighth decades of life—hypertension becomes more common in women than in men. This shift may partially result from the loss of estrogen during menopause, which leads to increased sympathetic activity and heightened adrenergic vasoconstrictor responsiveness (Joyner et al., 2016).

While this research has several strengths—such as the separate analysis of blood pressure status and other parameters by sex and sport type, the use of both BMI and BSA, and the assessment of SBP, DBP, and MAP—it also has some limitations. These include the cross-sectional nature of the study, a relatively small sample size for both male and female study participants, the exclusion of body composition parameters – Dewey, Rosenthal, Murphy Jr, Froelicher, & Ashley (2008) strongly argue that lean mass is the best predictor of cardiovascular

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parameters, particularly blood flow. Furthermore, the study lacks data on factors that could influence blood pressure values, such as medication, supplement use, tobacco and alcohol consumption, illicit substance use, diet, salt intake, psychosocial stressors, family history, etc. (Karpinos, Roumie, Nian, Diamond, & Rothman, 2013). Despite these limitations, the findings, especially concerning male participants, underscore the need for increased awareness, prevention, and timely management of high blood pressure in young adults, even those who are physically active and participate in sports, whether professionally or recreationally. The first step in addressing high blood pressure should include non-pharmacological interventions such as reducing salt intake, engaging in moderate physical activity, losing weight if obese, avoiding nicotine and alcohol, ensuring adequate sleep, adopting healthier dietary habits, and discontinuing supplements, anti-inflammatory drugs, or illicit substances (Niebauer, Boerjesson, Carre, Caselli, Palatini, Quattrini et al., 2018; Williams, Mancia, Spiering, Agabiti Rosei, Azizi, Burnier et al., 2018). Additionally, increased potassium intake and endurance exercises, if not already part of the routine, may also be beneficial (Niebauer et al., 2018; Williams et al., 2018; Wheton, He, Cutler, Brncati, Appel, Follmann, & Klag, 1997; according to Schweiger et al., 2021). If lifestyle modifications do not sufficiently reduce blood pressure within three months, antihypertensive medication should be considered.

CONCLUSION

The results of this research indicate that the situation is not harmless, at least when it comes to male athletes, regardless of the type of the sport, and regarding blood pressure status based on SBP and DBP values, which is a common practice. However, MAP values paint a more favorable picture, suggesting that the prevalence of hypertension is low among athletes. We certainly believe that this problem needs a more serious approach to managing and lowering blood pressure, primarily through non-pharmacological methods such as dietary adjustments, appropriate supplementation, and training load management – both type and volume. The statistically significant sex differences observed are unsurprising, given substantial evidence that androgenic hormones, such as testosterone, significantly contribute to sex-based differences in blood pressure regulation.

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