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RELATIONSHIP BETWEEN RUFFIER INDEX-DERIVED FITNESS LEVELS AND RESTING CARDIOVASCULAR PERFORMANCE IN YOUNG ADULTS

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ВЗАЄМОЗВ'ЯЗОК РІВНЯ ФІЗИЧНОЇ ПІДГОТОВКИ ЗА ІНДЕКСОМ РУФ'Є З ПОКАЗНИКАМИ СЕРЦЕВО-СУДИННОЇ СИСТЕМИ У МОЛОДИХ ДОРОСЛИХ

ABSTRACT

Purpose of the work. Physical fitness plays a crucial role in cardiovascular health, influencing stroke volume (SV), cardiac output (CO), heart rate (HR), and blood pressure. The Ruffier Index (RI) is a simple, field-based measure of cardiovascular efficiency, but evidence linking RI-assessed fitness to resting SV and CO in young adults is limited. This study aimed to investigate the relationship between RI-derived fitness levels and resting cardiovascular parameters (SV, CO, HR, SBP, DBP) in healthy young adults, and to examine potential sex-specific differences.

Methodology. A cross-sectional study was conducted with 51 healthy students (28 women, 23 men) from Pomeranian University in Słupsk, Poland (mean age: 20.8 ± 4.2 years for women; 19.9 ± 2.9 years for men). Physical fitness was classified using the RI into very good, good, average, and poor categories. Resting SBP, DBP, HR, SV, and CO were measured under standardised conditions. SV was calculated using the Starr formula, and CO was derived from SV × HR. Statistical analyses included ANOVA, post hoc Tukey tests, Pearson correlations, and linear/multivariate regression models with sex and blood pressure as covariates.

Scientific novelty. Most participants demonstrated average fitness, with very good fitness observed only in one male participant. Stroke volume decreased progressively as fitness declined in both sexes, while cardiac output increased among participants with lower fitness, indicating compensatory mechanisms via increased heart rate. Women with poor fitness had the highest resting CO (5485 ± 940 ml/min) and lowest SV (57.4 ± 7.9 ml), while men with poor fitness had CO of 5418 ± 510 ml/min and SV of 63.4 ± 3.1 ml. Significant negative correlations were found between RI and SV (women: $r = -0.52$; men: $r = -0.48$), and moderate positive correlations between RI and CO (women: $r = 0.46$; men: $r = 0.41$). Linear and multivariate regression confirmed RI as a significant predictor of SV and CO ($p < 0.01$). Sex differences were observed, with men exhibiting higher SV and slightly higher SBP.

Conclusions. Higher RI-assessed fitness is associated with greater stroke volume, lower cardiac output at rest, and more efficient myocardial function. Individuals with lower fitness compensate via increased HR, resulting in higher cardiovascular workload. These findings highlight the utility of RI as a practical tool for assessing cardiovascular efficiency in young adults and reinforce the importance of promoting regular physical activity to enhance cardiac function. Future studies should involve larger, longitudinal cohorts and include comprehensive physiological assessments.

Key words: Ruffier Index, physical fitness, stroke volume, cardiac output, resting heart rate, blood pressure, young adults, cardiovascular efficiency

АНОТАЦІЯ

Мета роботи. Фізична підготовка відіграє ключову роль у здоров'ї серцево-судинної системи, впливаючи на ударний об'єм (SV), серцевий викид (CO), частоту серцевих скорочень (HR) та артеріальний тиск. Індекс Руф'є (RI) є простим польовим методом оцінки ефективності серцево-судинної системи, проте дані про взаємозв'язок RI та показників SV і CO у молодих дорослих обмежені. Дослідження було спрямоване на вивчення взаємозв'язку між рівнем фізичної підготовки за RI та показниками серцево-судинної системи у стані спокою (SV, CO, HR, SBP, DBP) у здорових молодих дорослих, а також на виявлення можливих статевих відмінностей.

Методологія. Проведено поперечне дослідження за участю 51 здорового студента (28 жінок, 23 чоловіки) Поморського університету в Слупську, Польща (середній вік: 20,8 ± 4,2 років у жінок; 19,9 ± 2,9 років у чоловіків). Фізична підготовка класифікувалася за RI на категорії «дуже добра», «добра», «середня» та «слабка». Вимірювалися SBP, DBP, HR, SV і CO за стандартизованих умов у стані спокою. SV розраховувався за формулою

Старра, CO – як добуток SV × HR. Статистичний аналіз включав ANOVA, постхок-тести Тьюкі, кореляції Пірсона та лінійні/мультиваріатівні регресії з урахуванням статі та артеріального тиску.

Наукова новизна. У більшості учасників спостерігався середній рівень фізичної підготовки, дуже високий – лише у одного чоловіка. У обох статей ударний об'єм знижувався зі зменшенням рівня фізичної підготовки, тоді як серцевий викид зростав у учасників з низькою підготовкою, що свідчить про компенсаторні механізми через підвищення частоти серцевих скорочень. Жінки з слабкою фізичною підготовкою мали найвищий CO у стані спокою (5485 ± 940 мл/хв) та найнижчий SV (57,4 ± 7,9 мл), у чоловіків з слабкою підготовкою CO становив 5418 ± 510 мл/хв, а SV – 63,4 ± 3,1 мл. Виявлено значущу негативну кореляцію між RI та SV (жінки: r = −0,52; чоловіки: r = −0,48) та помірну позитивну кореляцію між RI та CO (жінки: r = 0,46; чоловіки: r = 0,41). Регресійний аналіз підтвердив RI як значущий предиктор SV та CO (p < 0,01). Статеві відмінності виявилися у вищому SV та дещо вищому SBP у чоловіків.

Висновки. Вищий рівень фізичної підготовки за RI асоціюється з більшим ударним об'ємом, меншим серцевим викидом у стані спокою та більш ефективною роботою серця. У осіб з нижчим рівнем підготовки серцевий викид підтримується за рахунок підвищення HR, що збільшує серцево-судинне навантаження. Результати підтверджують корисність RI як простого інструменту оцінки серцево-судинної ефективності у молодих дорослих та підкреслюють важливість регулярної фізичної активності для підтримки серцевої функції. Подальші дослідження мають включати більші когорти та довготривалі спостереження з комплексними фізіологічними вимірюваннями.

Ключові слова: індекс Руф'є, фізична підготовка, ударний об'єм, серцевий викид, частота серцевих скорочень у стані спокою, артеріальний тиск, молоді дорослі, ефективність серцево-судинної системи

Introduction

Physical fitness has a strong influence on cardiovascular health, encompassing the functional capacity of the heart, blood vessels and skeletal muscles to supply oxygen during sustained physical activity. Regular aerobic exercise induces well-documented structural and functional adaptations in the cardiovascular system. These include increased stroke volume (SV), enhanced ventricular compliance, improved diastolic filling and more efficient autonomic regulation of heart rate (HR) (Seo et al., 2023; Dores et al., 2024; Dou, 2026). These adaptations reduce cardiac workload at rest and enhance systemic perfusion during rest and exercise, thereby contributing to long-term cardiovascular resilience (Nystoriak and Bhatnagar, 2018).

Stroke volume (SV) and cardiac output (CO) are key indicators of cardiac efficiency. SV represents the volume of blood ejected by a ventricle during a single contraction, while CO denotes the total volume of blood pumped per minute. Both parameters are influenced by physical fitness level, sex, age, and cardiovascular health status (Bruss and Raja 2022; King and Lowery, 2023). Higher fitness levels are generally linked to higher SV and lower resting HR, indicating more efficient myocardial function and improved oxygen delivery. Conversely, lower fitness levels often lead to compensatory increases in heart rate (HR) to maintain cardiac output (CO), which imposes higher cardiovascular stress and may reduce cardiac efficiency over time (Stickland et al., 2012; Roh et al., 2016; Nystoriak and Bhatnagar, 2018).

The Ruffier Index (RI) is a practical, field-based method of assessing the cardiovascular response to short-term exercise. It calculates cardiovascular efficiency based on resting heart rate (HR), post-exercise HR and recovery HR, providing a simple measure of aerobic fitness and autonomic cardiac regulation (Guo et al., 2018; Alahmari et al., 2020). Although the RI is widely used in educational and sports settings, evidence linking RI-assessed fitness to resting stroke volume (SV) and cardiac output (CO) in young adults is limited, particularly with regard to potential sex-specific differences in cardiac performance. Understanding these associations is crucial for identifying individuals with suboptimal cardiovascular efficiency and for guiding early interventions to improve cardiovascular health (Horn et al., 2015; Bassareo and Crisafulli, 2020).

This study investigated the relationship between physical fitness, as measured by the RI, and resting cardiovascular parameters (including SV, CO, HR and blood pressure) in healthy young adults. We hypothesised that higher RI-assessed fitness would be associated with greater SV, lower resting CO and improved cardiovascular efficiency overall. We also hypothesised that these relationships might differ between the sexes due to inherent physiological differences in cardiac structure, ventricular compliance and autonomic regulation.

Materials and methods

Study design and participants. This cross-sectional study included 51 participants (28 women and 23 men), all of whom were students at Pomeranian University in Słupsk, Poland. The mean age was 20.8 ± 4.2 years for women and 19.9 ± 2.9 years for men. All participants were healthy and free from known cardiovascular, metabolic or musculoskeletal disorders. They were also not taking any medications that could affect heart rate or blood pressure. They were instructed to avoid caffeine, nicotine and intense physical activity for at least 12 hours prior to testing.

Participants were classified according to their level of physical fitness using the Ruffier Index (RI). Among the women, 32.1 % were classified as having good fitness, 50.0 % as having average fitness, and 17.9 % as having poor fitness. Among the men, 4.3 % demonstrated very good fitness (n = 1), 39.1 % demonstrated good fitness (n = 9), 47.8 % demonstrated average fitness (n = 11), and 8.7 % demonstrated poor fitness (n = 2). Overall, most participants exhibited average fitness levels, whereas very good fitness was observed in only one male participant.

Assessment of physical fitness. Physical fitness was evaluated using the RI, which assesses cardiovascular efficiency in response to short-term exercise. The RI was calculated using the formula described by Jastrzębska (2010): IR = [(P + P1 + P2) – 200] / 10. Here, IR denotes the Ruffier Index, P represents the resting heart rate, P1 represents the heart rate measured immediately after exercise and P2 represents the heart rate recorded after one minute of recovery. The results were interpreted as follows: 0-0.1 points: very good fitness; 0.1-5.0 points: good fitness; 5.01-10.0 points: average fitness; >10.01 points: poor fitness. Based on the obtained RI values, women and men from different age groups were classified into categories reflecting their level of physical fitness.

Cardiovascular measurements. Resting systolic blood pressure (SBP), diastolic blood pressure (DBP) and heart rate (HR) were measured in standardised resting conditions. All measurements were taken between 8:00 and 11:00 a.m. in a quiet, temperature-controlled room (22-24°C). Participants were seated with their arms supported at heart level throughout the procedure. Each measurement was repeated three times at one-minute intervals and the mean value was recorded.

Stroke volume (SV), i.e. the volume of blood ejected by one ventricle during a single cardiac contraction, was calculated using the Starr formula: SV = 90.97 + 0.54 × pulse pressure − 0.57 × diastolic blood pressure − 0.61 × age. In this formula, pulse pressure is defined as the difference between systolic and diastolic blood pressure, and age is expressed in years. These equations enable the estimation of stroke volume at rest, which reflects the efficiency of the left ventricle during each cardiac cycle.

Cardiac output (CO), which represents the total volume of blood pumped by a ventricle in one minute, is an important indicator of cardiovascular performance. In resting conditions, CO averages approximately 6 litres per minute, though this varies depending on sex, age and physical fitness level. CO is calculated by multiplying SV by HR: CO = SV × HR. This calculation provides an indication of overall cardiac workload and circulatory efficiency at rest, enabling cardiovascular performance to be compared between individuals with different levels of physical fitness. For each participant, SV and CO values are presented as the mean ± standard deviation (SD).

Statistical analysis. The data were analysed separately for women and men. One-way analysis of variance (ANOVA) was used to determine the differences in resting systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), stroke volume (SV) and cardiac output (CO) across fitness categories. Effect sizes were calculated using eta-squared (η^2) to estimate the proportion of variance explained by fitness level. Post hoc comparisons were performed using the Tukey honest significance difference (HSD) test to identify specific differences between fitness groups. Pearson's correlation coefficients were calculated to assess the association between the Ruffier index and cardiovascular parameters (SV, CO, HR and SBP/DBP). Linear regression analysis was conducted to determine whether the Ruffier index significantly predicted resting stroke volume and cardiac output. A multivariate regression model including sex and blood pressure variables as covariates was also performed to examine independent predictors of cardiovascular performance. Prior to statistical testing, the assumptions of normality and homogeneity of variances were verified using Shapiro-Wilk and Levene's tests, respectively (Zar, 1999). Statistical significance was set at $p < 0.05$. All analyses were performed using Statistica, version 13.3 (TIBCO, Palo Alto, USA).

Results and discussion

Among the female participants (n = 30), the largest proportion (46.7 %) demonstrated an average level of physical fitness, followed by a good level (33.3 %). Meanwhile, 20.0 % were classified as having poor fitness and none achieved a "very good" level according to the Ruffier Index classification. Among the men (n = 23), most also demonstrated an average level of physical fitness (47.8 %), followed by good fitness (39.1 %). A smaller proportion (8.7 %) exhibited poor fitness, while 4.3 % achieved a very good level. Overall, average fitness predominated in both sexes, whereas very good fitness was only observed in men and represented the smallest subgroup. These findings suggest that the studied population was generally characterised by moderate cardiovascular fitness.

Resting systolic blood pressure (SBP), diastolic blood pressure (DBP), stroke volume (SV) and cardiac output (CO) were analysed according to sex and physical fitness level, as determined by the Ruffier Index (RI). The results are summarised in Table 1.

Table 1

Resting systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), stroke volume (SV) and cardiac output (CO) according to sex and physical fitness level assessed by the Ruffier Index. Values are presented as mean ± standard deviation (S.D.)

Sex	Fitness level	n	SBP, mmHg	DBP, mmHg	HR, bpm	SV (ml)	CO (ml/min)
Women	Good	9	111.9 ± 19.4	66.6 ± 7.2	71.9 ± 6.6	63.7 ± 6.2	4575 ± 540
Women	Average	14	109.9 ± 14.0	70.1 ± 7.7	81.9 ± 6.0	61.0 ± 7.3	4820 ± 810
Women	Poor	5	110.0 ± 6.9	75.2 ± 3.6	94.6 ± 4.7	57.4 ± 7.9	5485 ± 940
Men	Very good	1	109.0	76.0	63.0	53.9	3394
Men	Good	9	128.1 ± 10.6	67.7 ± 10.8	67.6 ± 3.5	72.8 ± 8.6	4870 ± 720
Men	Average	11	132.4 ± 24.1	72.0 ± 9.3	82.3 ± 8.0	70.1 ± 9.2	5655 ± 930
Men	Poor	2	119.5 ± 0.7	72.0 ± 1.4	88.5 ± 6.4	63.4 ± 3.1	5418 ± 510

Abbreviation: systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), stroke volume (SV), cardiac output (CO)

In women, stroke volume decreased progressively as fitness levels declined. Participants classified as having good fitness had a mean stroke volume (SV) of 63.7 ± 6.2 ml, whereas those with average fitness had slightly lower values (61.0 ± 7.3 ml). The lowest SV values were observed in the poor fitness group (57.4 ± 7.9 ml). This gradual reduction in stroke volume with decreasing fitness level may reflect diminished myocardial efficiency and reduced ventricular filling capacity in individuals with lower levels of cardiovascular conditioning.

Conversely, cardiac output increased with declining fitness levels. Women with good fitness demonstrated a mean cardiac output (CO) of approximately 4575 ml/min, while those in the average group exhibited 4820 ml/min. The highest values were observed among participants with poor fitness (5485 ml/min). This pattern suggests that individuals with poorer fitness compensate for lower stroke volume by increasing their heart rate in order to maintain adequate systemic perfusion at rest.

A similar pattern was observed in men. Those with good fitness demonstrated relatively high stroke volume values (72.8 ± 8.6 ml), while the average fitness group showed slightly lower values (70.1 ± 9.2 ml). Those with poor fitness exhibited an additional reduction in SV (63.4 ± 3.1 ml). These findings are consistent with the physiological adaptations that occur in response to regular physical activity, which typically enhance ventricular contractility and stroke volume.

Cardiac output was highest in the average fitness group of men (5655 ± 930 ml/min), followed by the poor fitness group (5418 ± 510 ml/min). Lower values were observed in the good fitness group (4870 ± 720 ml/min). The lower resting cardiac output observed in the good fitness group may reflect greater cardiovascular efficiency, whereby a higher stroke volume enables the heart to maintain adequate circulation with a reduced heart rate.

In women, resting systolic blood pressure remained relatively stable across fitness categories, with only minor differences between groups. However, diastolic blood pressure tended to increase with decreasing fitness, suggesting reduced vascular efficiency in individuals with poorer cardiovascular fitness. Elevated DBP in lower fitness categories may also indicate increased peripheral vascular resistance and reduced arterial compliance.

In men, SBP values were generally higher than in women across most categories, particularly in the average fitness group, where the highest mean values were observed. DBP values in men demonstrated less consistent variation across fitness categories. These sex-related differences in blood pressure parameters are often linked to variations in body composition, hormonal regulation and autonomic cardiovascular control.

A one-way ANOVA revealed a significant effect of physical fitness level on stroke volume in both women ($F2,27 = 6.84$, $p = 0.004$, $\eta^2 = 0.34$) and men ($F3,19 = 5.26$, $p = 0.008$, $\eta^2 = 0.45$). These effect sizes suggest that fitness level moderately to strongly influences cardiac stroke performance. The relatively high values of the partial eta squared (η^2) suggest that a considerable proportion of the variability in stroke volume can be explained by differences in physical fitness level among the participants.

Similarly, a significant effect of fitness level on cardiac output was observed (women: $F2,27 = 7.12$, $p = 0.003$; men: $F3,19 = 4.89$, $p = 0.011$). Post hoc Tukey analysis showed that individuals with poor fitness differed significantly from those with good fitness, primarily due to lower stroke volume and compensatory increases in cardiac output. These results suggest that the cardiovascular adaptations associated with higher fitness levels enable more efficient cardiac function at rest, characterised by a greater stroke volume and a reduced reliance on increased cardiac output.

Sex differences were also observed. Independent sample t-tests revealed that men had significantly higher stroke volumes than women ($p < 0.01$), whereas women had slightly lower SBP values across most fitness categories. This is consistent with the known physiological differences between the sexes, including larger cardiac dimensions, greater blood volume and higher muscle mass, which are typically observed in men. Prior to conducting ANOVA, the assumptions of normality and homogeneity of variances were verified using Shapiro–Wilk and Levene's tests, respectively. All statistical analyses were performed at a significance level of $p < 0.05$.

Pearson's correlation analysis revealed a significant negative correlation between the Ruffier Index and stroke volume in both women ($r = -0.52$, $p = 0.004$) and men ($r = -0.48$, $p = 0.016$). This suggests that lower physical fitness (i.e. higher RI values) is associated with reduced cardiac stroke efficiency. In practical terms, individuals with poorer cardiovascular fitness tend to eject a smaller volume of blood from the left ventricle during each cardiac cycle.

A moderate positive correlation was observed between the Ruffier index and cardiac output (women: $r = 0.46$, $p = 0.012$; men: $r = 0.41$, $p = 0.039$), suggesting that individuals with poorer cardiovascular fitness experience compensatory increases in cardiac workload. This relationship likely reflects the physiological mechanism whereby reduced stroke volume is compensated for by an increase in heart rate in order to maintain adequate systemic blood flow at rest.

No significant correlations were found between the RI and systolic blood pressure in either sex. This suggests that resting SBP may be less sensitive to differences in physical fitness within the studied population, particularly among young or otherwise healthy individuals. The correlation analysis supports the concept that cardiovascular efficiency, as indicated by a higher stroke volume and a lower cardiac workload at rest, is associated with better physical fitness levels.

Linear regression analysis confirmed that the Ruffier Index significantly predicted stroke volume (β = −0.61, $p < 0.001$). The model explained 37% of SV variability ($R^2 = 0.37$). This relatively high coefficient of determination indicates that a substantial proportion of the variance in stroke volume can be attributed to differences in physical fitness as assessed by the Ruffier Index. The negative regression coefficient further confirms that higher RI values (indicating lower physical fitness) are associated with reduced stroke volume.

In a multivariate regression model including sex and blood pressure variables, the Ruffier Index remained a significant independent predictor of stroke volume (β = −0.58, $p < 0.001$) and cardiac output (β = 0.42, p = 0.009). These findings suggest that the association between the Ruffier Index and cardiac function persists even after adjusting for potential confounding variables such as sex and resting blood pressure. The regression analysis highlights the Ruffier Index as an important predictor of resting cardiovascular performance in the studied population.

The present findings demonstrate a clear relationship between physical fitness and cardiovascular performance, particularly with regard to stroke volume and cardiac output. Those in better physical condition exhibited higher stroke volume and lower cardiac output at rest, indicating greater myocardial efficiency. This pattern reflects the well-known physiological adaptation to regular physical activity whereby an increased stroke volume enables the heart to maintain adequate systemic circulation with fewer contractions per minute (González-Alonso et al., 2000; Asrar Ul Haq et al., 2015; Schierbauer et al., 2021).

The observed reduction in stroke volume among less fit individuals may indicate reduced myocardial contractility and lower ventricular filling capacity. Consequently, cardiac output is maintained through compensatory increases in heart rate, thereby increasing the overall cardiac workload. Such compensatory mechanisms are commonly observed in individuals with lower cardiorespiratory fitness and may lead to less efficient cardiovascular regulation at rest (Drzyzga et al., 2021; Farrell and Turgeon, 2023).

These findings are consistent with previous studies demonstrating that aerobic training enhances cardiac stroke volume, ventricular compliance, and autonomic regulation (Farrell and Turgeon, 2023; Bonganha et al., 2026). This results in improved cardiovascular efficiency and a reduced resting cardiac workload. Regular endurance activity is known to induce structural and functional cardiac adaptations, including increased left ventricular volume, improved diastolic filling, and enhanced parasympathetic regulation of heart rate (Martinez et al., 2021; Epelde, 2024).

The sex differences observed in the present study are also consistent with physiological expectations. Men had higher stroke volume values than women, which is likely due to greater cardiac mass, a higher circulating blood volume, and differences in body composition (Wooten et al., 2021; St Pierre et al., 2022). Additionally, hormonal factors and differences in haemoglobin concentration may contribute to the greater oxygen transport capacity typically observed in men (Haferanke et al., 2025). These results support the idea that higher levels of physical fitness are associated with more efficient cardiovascular function, characterised by a greater stroke volume, a lower resting cardiac workload, and improved haemodynamic regulation (Nystoriak and Bhatnagar, 2018).

Several previous studies have confirmed the effectiveness of the Ruffier or Ruffier-Dickson test in providing a simple assessment of cardiorespiratory fitness (CRF) in young people. A cross-sectional study of college students aged 18-23 demonstrated that most participants had moderate cardiovascular endurance according to the Ruffier-Dickson index. Specifically, nearly half of the subjects were classified as having "average endurance", while only a small proportion achieved "very good" results. These results imply that even among university students specialising in health-related subjects, optimal cardiorespiratory fitness is not universal, emphasising the importance of regularly monitoring and promoting physical activity in this group (Modi and Jain, 2024). The endurance category distribution observed in the study supports the idea that the Ruffier index can identify different levels of cardiovascular efficiency in young adults.

The association between cardio-respiratory fitness and cardiovascular, as well as anthropometric, risk factors has also been widely documented. Alahmari et al. (2020) demonstrated that CRF, as estimated by the Ruffier test, was significantly associated with several physiological and lifestyle-related variables. In particular, estimated VO_2 max showed an inverse relationship with age, body weight, body mass index, waist circumference, blood pressure and resting heart rate, and a positive correlation with physical activity levels and pulmonary function. Importantly, their multivariable analysis indicated that body weight and resting heart rate were independent predictors of CRF. These findings reinforce the idea that simple, field-based fitness tests can reflect broader physiological processes related to cardiovascular efficiency and metabolic health.

Age-related changes in cardiovascular functional capacity have also been reported among university students. In a study of female students aged 18-22, Chernenko et al. (2022) found that indices of cardiovascular and respiratory performance, such as the Ruffier index and heart rate responses to exercise, differed between academic years. The authors also reported that compensatory cardiovascular mechanisms appeared to be most efficient around the age of 21, as indicated by improved heart rate recovery after exercise. However, the proportion of students with satisfactory Ruffier index values increased with age, while the proportion demonstrating good cardiovascular performance decreased. These findings suggest that lifestyle factors during the university years may influence trajectories of cardiovascular fitness, particularly among female students.

Lifestyle-related factors also play a significant role in determining cardio-respiratory fitness in young adults. A large cross-sectional study of Pakistani university students showed that physical activity level, body weight, body mass index and resting heart rate were significantly associated with CRF, as assessed by the Ruffier-Dickson test (Ehsan and Asim, 2023). The authors emphasised that sedentary behaviours, such as prolonged screen time, can negatively impact cardiovascular fitness, even in otherwise healthy young individuals. These results highlight the importance of considering behavioural factors when interpreting CRF outcomes, and emphasise the value of simple screening tests in identifying individuals at risk of reduced cardiovascular fitness.

Further evidence from younger populations supports the relationship between body composition and cardiorespiratory performance. Studies conducted among children and adolescents have shown that overweight and obese individuals have significantly lower CRF levels than their normal-weight peers (Sepúlveda et al., 2025). In these groups, lower maximal oxygen consumption, a higher exercise heart rate and poorer recovery responses were observed, as reflected in worse Ruffier and Dickson index scores. Furthermore, individuals with lower CRF exhibited higher energy expenditure and greater perceived exertion during exercise. These findings suggest that excess body mass may increase cardiovascular strain during physical activity and impair recovery efficiency.

A large meta-analysis including more than 5,000 children and adolescents with overweight or obesity also confirmed the beneficial effects of exercise interventions on CRF (Men et al., 2025). This analysis showed that structured exercise programmes significantly improved several indicators of cardiovascular health, including maximal oxygen uptake, systolic and diastolic blood pressure, and resting heart rate. Notably, moderate-to-high-intensity exercise performed at least three times per week was associated with the greatest improvements in CRF. These results support the idea that regular physical activity is one of the most effective ways to improve cardiovascular efficiency and reduce long-term cardiometabolic risk.

These studies suggest that cardiorespiratory fitness is affected by the interplay of various physiological, behavioural and anthropometric factors. The Ruffier and Ruffier-Dickson indices provide a practical and accessible method of evaluating these relationships in large populations, particularly among students and young adults. Their ability to reflect variations in the cardiovascular response to exercise makes them suitable for use in both research and preventive health screening.Several limitations should be considered when interpreting the results. Firstly, some fitness subgroups had relatively small sample sizes, particularly among men with very good or poor fitness levels. This may limit statistical power. This may increase the risk of type II error and reduce the generalisability of the findings to broader populations. Secondly, the cross-sectional design prevents any causal inferences regarding the relationship between physical fitness and cardiovascular parameters. Therefore, the observed associations should be interpreted as correlational rather than causal.

A further limitation is related to the use of the Ruffier Index as the primary indicator of physical fitness. While it is a practical and widely used field test, it does not provide as precise an assessment of cardiorespiratory fitness as laboratory-based measures such as maximal oxygen uptake (VO_2 max). Future studies should include larger cohorts and longitudinal designs to confirm these findings. In addition, incorporating more comprehensive physiological assessments and controlling for potential confounding factors such as age, body composition and habitual physical activity levels could strengthen future analyses further.

Conclusions

This study clearly shows that there is a strong relationship between physical fitness, as measured by the Ruffier Index, and resting cardiovascular performance in both women and men. Those with higher fitness levels exhibited greater stroke volume and lower cardiac output at rest, indicating more efficient myocardial function and a reduced cardiac workload. Conversely, lower fitness levels were associated with reduced stroke volume and compensatory increases in heart rate, reflecting a higher cardiovascular burden required to maintain adequate systemic perfusion. These findings emphasise the physiological adaptations associated with regular physical activity, such as enhanced ventricular contractility, improved diastolic filling and more effective autonomic regulation of heart rate. The observed sex differences, with men exhibiting higher stroke volumes and slightly higher blood pressure values, align with recognised variations in cardiac mass, circulating blood volume, body composition, and haemoglobin concentration.

Statistical analyses, including ANOVA, correlation, and regression models, consistently confirmed that the Ruffier Index is a significant predictor of stroke volume and cardiac output, even when adjusting for sex and blood pressure. This emphasises the usefulness of simple, field-based fitness assessments for identifying individuals with suboptimal cardiovascular efficiency.

Despite these important insights, the findings should be interpreted in light of certain limitations. Small sample sizes in some fitness subgroups (particularly men with very good or poor fitness) and the cross-sectional study design limit statistical power and preclude causal inferences. Additionally, while the Ruffier Index is practical, it provides a less precise measure of cardiorespiratory fitness than laboratory-based assessments such as VO_2 max.

Future research should employ larger, longitudinal cohorts and incorporate comprehensive physiological measurements in order to confirm and extend these findings. Nevertheless, this study provides compelling evidence that higher physical fitness is linked to more efficient cardiovascular function. This supports the idea that promoting regular physical activity is a vital strategy for maintaining cardiovascular health and reducing cardiac workload at rest.

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Заява про доступність даних / Data Availability Statement

Дані, що підтверджують результати цього дослідження, можна отримати у відповідального автора за обґрунтованим запитом / The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Заява інституційної ревізійної ради / Institutional Review Board Statement

Дослідження було проведено відповідно до етичних стандартів Гельсінської декларації та схвалено Комітетом з біоетики при Окружній медичній палаті в Гданську, Польща (номер схвалення KB-2/26). Усі учасники надали письмову інформовану згоду перед участю / The study was conducted in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Bioethics Committee at the District Medical Chamber in Gdańsk, Poland (Approval No. KB-2/26). All participants provided written informed consent prior to participation.

Заява про інформовану згоду / Informed Consent Statement

Інформовану згоду було отримано від усіх учасників дослідження. Учасників було повністю поінформовано про мету, процедури та потенційні ризики дослідження, і вони добровільно погодилися на участь / Informed consent was obtained from all subjects involved in the study. Participants were fully informed about the purpose, procedures, and potential risks of the study, and they voluntarily agreed to participate.

Конфлікт інтересів / Conflict of interest

Автори Наталія Кургалюк та Галина Ткаченко є членами редакційної колегії *Biota. Human. Technology*. Вони не брали участі в процесі прийняття редакційних рішень, рецензування чи прийняття цього рукопису. Автори не мають інших конфліктів інтересів, про які слід зазначити / Authors Natalia Kurhaluk and Halina Tkaczenko are the members of the editorial board of Biota. Human. Technology. They were not involved in the editorial decision-making, peer review, or acceptance process for this manuscript. The authors have no other conflicts of interest to note.

Декларація про генеративний штучний інтелект і технології на основі штучного інтелекту в процесі написання / Declaration on Generative Artificial Intelligence and AI-enabled Technologies in the Writing Process

Автори заявляють, що для створення, редагування або суттєвого перегляду змісту цього рукопису не використовувалися генеративний штучний інтелект (ШІ) або технології на базі ШІ. Усі написання, аналіз та інтерпретація були проведені виключно авторами / The authors declare that no generative artificial intelligence (AI) or AI-enabled technologies were used to create, edit, or substantively revise the content of this manuscript. All writing, analysis, and interpretation were conducted solely by the authors.

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