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THE RELATIONSHIP BETWEEN POSTURAL STABILITY AND DYNAMIC FUNCTION OF THE LOWER LIMBS IN UNIVERSITY STUDENTS WITH DIVERSE PROFESSIONAL FOCUSES

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Abstract The aim of this study was to examine the correlation between postural stability and the dynamic function of the lower limbs in university students, and to identify differences based on their academic specialization. The sample consisted of 68 University of Presov students (age: 23.06±2.48; BMI: 22.81±2.50). The sample was divided according to students' academic focus: Faculty of Health Care students (FHC) (n=32; age: 21.88±0.71; weight: 67.44±12.37 kg; height: 1.72±0.08 m; BMI: 22.62±2.80) and Faculty of Sport students (FS) (n=36; age: 24.11±2.98; weight: 72.44±10.17 kg; height: 1.77±0.09 m; BMI: 22.99±2.23). For monitored parameters evaluating, we have used the Freemed baropodometric platform and Y balance test (YBT). The YBT scores of FS students were l.sin.=97.31±6.41; l.dx.=96.42±7.76, and of FHC students were l.sin.=87.49±7.24; l.dx.=86.50±8.10. No significant differences were found between the composite scores of the left ($p=0.48$) and right ($p=0.80$) lower limbs in both groups ($p<0.05$). The correlation between postural stability and lower limb dynamic function showed no significance (l.sin. $R2=0.017$; l.dx.=$R2=0.010$). The results of the study indicate a very weak correlation between postural stability and dynamic function of the lower limbs among the students tested.

Key words: Y balance test, baropodometric platform, balance, postural system

Introduction

In the human body, the lower limbs bear the greatest load during standing, and the distribution of this pressure across the feet directly affects the stability of the musculoskeletal system (Mounika et al., 2022). Foot pressure distribution analysis plays a significant role in healthcare, clinical rehabilitation, and sports training (Rajendran et al., 2021). Plantar pressure distribution is a key parameter that provides insights into an individual's postural changes (Żurawski et al., 2022; Serrato-Pedrosa et al., 2024). As a key structure involved in weight distribution and force transfer, the foot represents a fundamental component of the body's supportive function. Its condition has a direct impact on postural health and overall stability (Bendíková & Balint, 2023). Owing to its structure and arch system, it ensures the transmission of forces between the ground and the higher segments of the musculoskeletal system. When the function of the arches is impaired, a chain of muscular imbalances occurs, which may influence the alignment of the pelvis, the spine, and consequently overall posture (Myers, 2009; Véle, 2006). The stability and proper activation of the foot muscles also determine effective proprioception, which is crucial for maintaining balance and preventing overload. Therefore, foot health is considered a key determinant of postural stability and the functional integrity of the musculoskeletal system (Palaščáková Špringrová, 2018).

Postural stability is fundamentally defined as the ability to maintain an upright posture within the body's base of support and reflects the efficiency of neuromuscular control during various activities (Lee & Lin, 2007). Its quality is influenced by factors such as muscle co-activation, joint stiffness, and external loading conditions (Shabani, 2016). These mechanisms highlight that postural stability is not merely a reflexive process but a complex skill based on the interaction of dynamic sensorimotor processes. This perspective is in line with Horak's (2006) conceptualization of postural control as an integrated, adaptive system. Postural stability and balance are therefore central to optimal movement and functional performance in daily life and sports. They determine the ability to maintain the body's center of mass within the base of support in both static and dynamic tasks (Nusseck & Spahn, 2020).

The educational environment provides an opportunity for the systematic implementation of exercises aimed at correcting posture and supporting lower limb function. Physical and sports education, when designed with an emphasis on postural health, can contribute to the elimination of muscular imbalances, enhancement of proprioception, and consolidation of proper movement patterns (Bendíková, 2018). Appropriately selected sensorimotor and balance exercises promote the automatization of correct motor patterns and positively influence both trunk and foot stability (Biancalana et al., 2020; Palaščáková Špringrová, 2018). Their regular inclusion in the educational process represents an effective tool for the prevention of musculoskeletal disorders and supports the development of an active and healthy lifestyle among university students (Bendíková, 2020; Bendíková & Balkó, 2022; Bendíková et al., 2024).

Postural control imbalances are relatively common among university students, with static impairments occurring more frequently than dynamic ones. The primary risk factors include high body mass index (BMI) and physical inactivity (Khanzada et al., 2024). Based on this theoretical background, the aim of this study was to examine the relationship between postural stability and the dynamic function of the lower limbs among university students and to identify differences based on their professional field.

Methods

This research was approved by the Ethics Committee of the University of Presov in Presov (No. ECUP062024PO). All participants provided written consent and were made aware that there would be no financial cost or incentive for participation at the time of enrolling in the study. The research carried no risk of violating ethical principles.

Participants

The study sample consisted of 68 participants (N=68) with a mean age of 23.06±2.48 years. The average BMI of the sample was 22.81±2.50. The participants were divided into two groups: group S1 included respondents from the Faculty of Health Care (FHC) at the University of Presov (n=32; 28 female and 4 men), and group S2 included respondents from the Faculty of Sports (FS) at the same university (n=36; 10 female and 26 men). The average age of group S1 (physiotherapy students) was 21.88±0.71 years, with a mean height of 1.72±0.08 m, mean body weight of 67.44±12.37 kg, and an average BMI of 22.62±2.80. Group S2, composed of physical education students, had a mean age of 24.11±2.98 years, mean height of 1.77±0.09 m, mean body weight of 72.44±10.17 kg, and an average BMI of 22.99±2.23. All the specific values, including standard deviations, are presented in Table 1. Numerical data are rounded to two decimal places.

Table 1. General characteristics of the study sample

Parameter	S1_FHC ($\bar{x}$±SD)	S2_FS ($\bar{x}$±SD)	Total ($\bar{x}$±SD)
Age	21.88±0.71	24.11±2.98	23.06±2.48
Body height (m)	1.72±0.08	1.77±0.09	1.75±0.09
Body weight (kg)	67.44±12.37	72.44±10.17	70.09±11.45
BMI	22.62±2.80	22.99±2.23	22.81±2.50
n	32	36	68

Notes: SD – standard deviation; $\bar{x}$ – mean, BMI – Body mass index; n – sample size

The Physiotherapy study program is characterised by lower overall physical intensity and a predominance of therapeutic and rehabilitative movement activities. In the first year, students complete approximately 8 hours of practical classes per week, focused on physical therapy, basic massage techniques, clinical practice and introductory therapeutic procedures. A substantial portion of the curriculum consists of extensive theoretical preparation (anatomy, physiology, pathology, kinesiology, diagnostics), complemented by specialised practical subjects such as kinesiotherapy, rehabilitative exercise, therapeutic interventions, diagnostic methods and ergotherapy. As a result, the movement profile of physiotherapy students is primarily health-oriented and rehabilitative, with comparatively lower physical load. In contrast, the Physical Education Teacher Training program is defined by higher levels of physical activity and sports-related demands, as students engage in the development of motor abilities, sports preparation and instruction of physical activities. Already in the first year, they complete around 8 hours of practical sports classes weekly (gymnastics, athletics, sport specialisation, health-oriented physical education). The core of the program consists of sport training, sport-specific didactics, practical courses in various sports, and teaching practice. Overall, the two programs demonstrate distinct movement profiles, physiotherapy emphasises therapeutic, health-oriented movement with lower physical intensity, whereas physical

education training emphasises sport performance, high physical activity levels and practical movement load. Data on physical activity and extracurricular activities were not collected.

Procedures and measurement

To assess the dynamic function of the lower limbs, we used the Y Balance Test (lower quarter), which is commonly applied in practice to measure dynamic stability and identify potential lower limb injury risk. It is a modified version of the Star Excursion Balance Test, designed to improve its practicality and accessibility.

Before testing, leg length was measured using a tape measure, as it is required to calculate the composite score (normalised values according to the length of the lower limb). Leg length was measured from the anterior superior iliac spine to the medial malleolus.

The Y Balance Test requires the participant to maintain balance, strength, coordination, and stability on one lower limb while reaching the other lower limb as far as possible along a Y-shaped measuring surface in three directions: anterior, posterolateral, and posteromedial. Each participant performs three test trials with each lower limb to master the correct execution. The formal testing began with three trials in the anterior direction, followed by switching the stance leg. The participant continues with three trials in the posteromedial and posterolateral directions. The best result from each direction was used for analysis. The composite score is calculated as the sum of the results from the 3 directions tested/3×limb length×100. The result is expressed as a percentage (Plisky et al., 2009).

Foot pressure distribution was analysed using a baropodometric platform (FreeMed Maxi, Sensor Medica, Italy). The assessment included the percentage load on the right and left foot, as well as the load distribution between the forefoot and rearfoot of both feet. The physiological distribution of load is defined as 50% of body weight on each foot (tolerance ±3%). For the anteroposterior distribution, the physiological load is 45% on the forefoot (tolerance ±3%) and 55% on the rearfoot (tolerance ±3%). Values outside these tolerance ranges are considered pathological foot loading. Before the test, participants were informed about the procedure and instructed not to adjust their stance, but to adopt their natural static posture. Each test lasted 5 seconds and was automatically evaluated using software provided by Sensor Medica (Italy).

Hypotheses

- Students of the Faculty of Sports will achieve better results in the Y Balance Test composite score compared to students of the Faculty of Health Care.
- There is a statistically significant correlation between plantar pressure and the composite score of the Y Balance Test in the tested students.
- There are statistically significant differences in plantar pressure distribution between students of the Faculty of Sports and the Faculty of Health Care.

Statistical analysis

The D'Agostino's K-squared test was used to verify the normal distribution of the data. Based on this result, we subsequently applied appropriate parametric statistical methods. A two-sample Fisher's F-Test for variance was used to evaluate the hypotheses. The relationship between total foot load and dynamic balance was analysed using simple linear regression.

Results

Analysis of the Dynamic Function of the Lower Limbs in University Students

Table 2 presents the Y Balance Test performance values for group S1 and S2 in all three tested directions (anterior, posteromedial, and posterolateral), as well as the composite score.

Table 2. Descriptive statistics of Y balance test

		S1					S2				
		$\bar{x}$	Med	SD	Min	Max	$\bar{x}$	Med	SD	Min	Max
Anterior	R	67.28	67.00	5.17	59.00	76.00	64.64	65.00	5.78	56.00	79.00
	L	67.03	67.00	5.65	55.00	75.00	65.81	65.50	5.83	55.00	80.00
Postero-medial	R	95.03	93.50	8.79	73.00	112.00	111.06	111.00	13.57	83.00	141.00
	L	95.31	94.50	5.77	88.00	110.00	111.39	110.50	10.90	90.50	140.00
Postero-lateral	R	90.56	89.50	8.29	78.00	107.00	107.79	106.00	12.72	83.00	140.00
	L	92.19	90.50	8.09	77.00	108.00	108.63	107.00	12.20	92.00	135.00
Composite score	R	86.50	86.28	8.10	74.92	110.21	96.42	96.21	7.76	74.33	114.43
	L	87.49	87.72	7.24	75.42	107.66	97.31	95.92	6.41	86.67	109.97

Notes: R – right lower limb; L – left lower limb; $\bar{x}$ – mean; med – median; SD – standard deviation; min – minimum; max – maximum

Based on the results of the Y balance test, we can observe differences in the achieved values between S1 and S2 groups. On average, respondents from S2 group achieved higher values in two (posteromedial and posterolateral) out of three tested directions (anterior, posteromedial and posterolateral) as well as in the composite score. Better results in tested directions may indicate superior dynamic balance and stability in group S2.

We assumed a statistically significant difference between the tested groups S1 and S2. To evaluate this assumption, a two-sample Fisher's F-Test for variance was used. We found out that the difference between the left lower limb composite score ($p=0.48$) and the right lower limb composite score in both groups ($p=0.80$) was not statistically significant ($p<0.05$). This means that the differences found between the test samples were not statistically significant.

Analysis of Plantar Pressure distribution in University Students

Table 3 presents the descriptive statistical variables obtained from the baropodometric platform for both groups. Analysis of the baropodometric data revealed differences in plantar pressure distribution between the groups. Higher mean values of total foot load were observed on the left foot in group S1, and on the right foot in group S2. In terms of forefoot loading, group S1 showed higher values for both the left and right foot. In contrast, the rearfoot load values were higher in group S2 for both feet.

Table 3. Descriptive statistics of plantar pressure distribution

		S1			S2		
		Global	**Forefoot**	**Rearfoot**	**Global**	**Forefoot**	**Rearfoot**
x̄	R	49.09	50.31	49.71	51.00	49.25	50.75
	L	50.91	53.01	46.99	49.00	47.31	52.69
SD	R	4.55	9.81	9.83	3.18	8.76	8.76
	L	4.55	9.78	9.78	3.18	8.58	8.58
Min	R	43.30	31.30	36.30	42.00	29.00	33.00
	L	40.70	37.20	28.40	43.00	32.00	38.00
Max	R	59.30	63.70	68.70	57.00	67.00	71.00
	L	56.70	71.60	62.80	58.00	62.00	68.00
Med	R	48.90	51.70	48.30	51.50	51.00	49.00
	L	51.10	53.05	46.95	48.50	45.50	54.50

Notes: L – left foot; R – right foot; x̄ – mean; SD – standard deviation; min – minimum; max – maximum; Med – Median

Fisher's F-test for variance showed a statistically significant difference between groups only in global plantar pressure on the left and right leg (p=0.04). Sample S1 demonstrated higher plantar loads on the left leg, whereas sample S2 demonstrated higher plantar loads on the right leg. For the other tested parameters (forefoot and rearfoot), the differences between the groups were not statistically significant (Table 4).

Table 4. Comparison of differences between S1 and S2 in plantar pressure distribution

	S1			S2		
	Global LF	Global RF	Forefoot LF	Forefoot RF	Rearfoot LF	Rearfoot RF
F	2.05	2.05	1.30	1.25	1.30	1.26
|F|	1.99	1.99	1.99	1.99	1.99	1.99
p-value	0.04	0.04	0.45	0.51	0.45	0.51
α	0.05	0.05	0.05	0.05	0.05	0.05

Notes: LF – left foot; RF – right foot; F – observed value; |F| – critical value; α – significance level

The relationship Between Y Balance Test Performance and Plantar Pressure

Simple linear regression was used to analyse the relationship between the total plantar pressure and the composite Y balance test score as the independent variable. We assumed that a higher foot load would correlate with a higher composite score. The data were processed by identifying the lower limb with the higher total load (left or right), and this value was used in the correlation with the corresponding composite score. Two participants with no difference in foot load between limbs were excluded from the analysis.

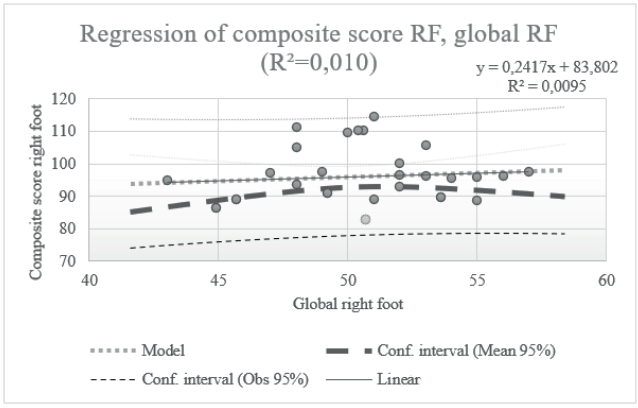


Figure 1. Correlation graph of the composite score and total load of the right foot

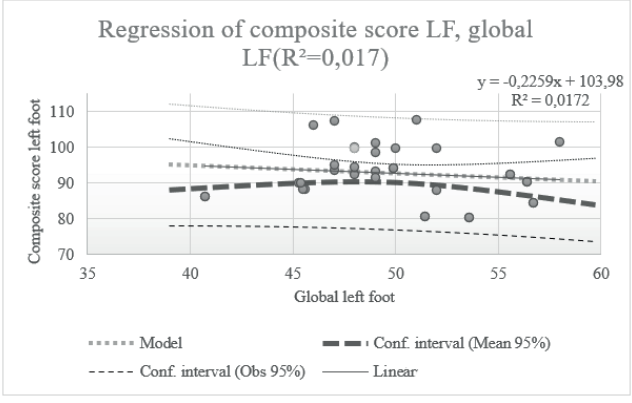


Figure 2. Correlation graph of the composite score and total load of the left foot

Analysis of the correlation between the total foot load and the composite Y balance test score showed a very low correlation for both lower limbs. This means that there is no clear relationship between higher plantar pressures and better performance in the Y balance test. These results suggest that the ability to maintain dynamic balance is not directly dependent on the distribution of plantar pressures but may be influenced by other factors.

Discussion

The study aims to verify the relationship between postural stability and dynamic function of the lower limbs of university students and to identify differences depending on their professional focus. The study employed standardized, validated, and reliable measurement methods to assess both postural stability and the dynamic function of the lower limbs, thereby minimizing the risk of subjective bias. By analysing both static and dynamic aspects of the locomotor system, the research provided a multidimensional perspective on lower-limb functional

status. This approach enhances the value of the study, as it highlights the distinct nature of postural regulation and dynamic performance. Furthermore, the research brings new insights into the postural health of young adults – a population often perceived as "movement-healthy," despite the increasing prevalence of sedentary behaviour in this age group. The study thus responds to a current societal need to monitor and better understand the movement health of university students.

A comparison of physical fitness between physiotherapy and physical education students reveals significant differences in fitness levels and health-related parameters. Although both groups are expected to maintain a high level of physical fitness due to the demands of their future professions, the findings suggest that physical education students generally demonstrate better physical fitness than their physiotherapy counterparts (Bello et al., 2016; Dutta & Ghosh, 2016; Juhkam & Vaher, 2020). Physical activity and athletic performance may influence an individual's dynamic balance (Huang et al., 2023). For these reasons, we assumed that there would be a statistically significant difference in the Y Balance Test scores – representing the dynamic function of the lower limbs – between the tested groups, in favour of students with a physical education background. Although the Y Balance Test results showed differences between groups S1 and S2, with participants from group S2 achieving higher average values in two out of three tested directions and in the composite score, statistical analysis did not confirm the significance of these differences.

A statistically significant difference between the groups was found in total plantar pressure on the left and right foot, while the differences in the other tested parameters (forefoot and rearfoot) were not statistically significant. Current scientific evidence identifies several factors contributing to differences in plantar pressure distribution. Body weight, body composition, and factors such as height, shoe size, and BMI influence the distribution of plantar pressure. Older individuals tend to exhibit different characteristics compared to younger ones, and clear differences in pressure distribution have also been observed between males and females (Lin et al., 2023; Dikhtyarenko et al., 2024; Patel & Balaganapathy, 2024). Muscular imbalance also plays a significant role – greater strength of the knee flexors compared to the extensors leads to increased heel pressure, while greater strength of the knee extensors is associated with increased pressure on the forefoot (Akaras et al., 2024; Kozel et al., 2020). According to Kozel et al. (2024), differences in plantar pressure distribution may also be influenced by the type of sports activity and postural adaptations, particularly shifts in the centre of gravity.

The correlation analysis did not demonstrate any dependence between total foot load and the composite score for either the right or left lower limb. Since no statistically significant relationship was found in either case, our initial assumption, that greater plantar pressure would be associated with a higher Y Balance Test composite score, was not confirmed. Similar results were reported by Sikora et al. (2020), who concluded that Y Balance Test outcomes and baropodometric platform results are weakly correlated in adolescents. These findings suggest that the Y Balance Test and baropodometric platform assess different aspects of balance in this age group. Similarly, Meiners and Loudon (2020) found no significant relationship between dynamic and static balance tests. They concluded that dynamic and static postural assessments provide different types of information in the context of overall balance evaluation. Research also indicates that factors such as limb dominance and gender may play an important role in balance assessment. This suggests that a multidimensional approach is essential for a comprehensive evaluation of balance (Arin-Bal et al., 2023).

The findings support the need for systematic assessment of postural stability and functional performance in university students, regardless of their field of study. Since no clear association between postural stability and the

dynamic function of the lower limbs was confirmed, it is recommended to approach these domains independently and in a targeted manner. Intervention programs should therefore distinguish between (1) training focused on balance, sensorimotor control, and postural regulation, and (2) training aimed at strength, speed, and dynamic lower-limb performance. In educational and practical settings, it is advisable to incorporate instruction related to ergonomics, posture, correct movement patterns, management of unilateral loading, and the prevention of musculoskeletal complaints. To support a deeper understanding of related functional relationships, diagnostic procedures should be expanded to include additional functional and behavioural variables such as posture analysis, muscle imbalances, flexibility, sedentary behaviour, and overall physical activity levels.

Limitations and future directions

The main limitations of the study include the measurement accuracy of the baropodometric platform, which may have been affected by slight movements of the participants or sensor sensitivity. Variability in static posture, despite instructions not to adjust body alignment, may have influenced plantar pressure distribution. The short duration of the test (5 seconds) may not have been sufficient to capture natural postural fluctuations. The homogeneity of the sample in terms of age limits the generalisability of the results to a broader population. Individual biomechanical differences, as well as the effects of fatigue or learning, may have affected performance in the Y Balance Test. Differences in physical fitness between the groups may have affected the comparability of the results. The results should be interpreted with these limitations.

Conclusion

Based on the data analysis, we concluded that there is only a very weak or almost no relationship between postural stability and the dynamic function of the lower limbs in university students with different professional focuses, as confirmed by a low correlation coefficient. We found that the variables do not demonstrate a strong enough interdependence to influence each other in a meaningful way. We assume that one of the limitations of the study, which may have influenced the results, was the heterogeneity of the sample, including differences in physical fitness levels among students. Long-term training may also have influenced the results, reducing the generalisability of the findings to the broader population of university students. In addition, the short duration of the study may have limited the capture of longitudinal relationships between variables.

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MECHANISMS OF EXERCISE LIMITATION DURING INCREMENTAL TESTING IN POSTMENOPAUSAL OBESITY: A CARDIOPULMONARY CASE SERIES

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Abstract **Background:** Obese postmenopausal women are at high risk for cardiometabolic disease, yet the specific physiological patterns of their exercise intolerance remain poorly described. Emerging evidence suggests that this intolerance reflects the combined effects of reduced cardiovascular reserve, impaired metabolic flexibility, and autonomic dysregulation, which may be detectable using cardiopulmonary exercise testing (CPET). This case series aimed to characterize the cardiorespiratory and metabolic responses to graded exercise in this population.

Case summary: We present nine sedentary, obese postmenopausal women (mean age 56.78±9.02 years; BMI 33.87±3.8 kg/m²) who underwent maximal cardiopulmonary exercise testing using graded cycle ergometry. Key parameters (VO_2, VCO_2, respiratory exchange ratio (RER), heart rate (HR), and O_2 pulse) were recorded at rest (Rest.3), the anaerobic threshold (AT), maximum workload (Wmax), and at 1 (Rec.1) and 3 (Rec.3) minutes into recovery. Results revealed severely impaired functional capacity, with peak oxygen uptake (VO_2max) ranging from (4±1) to (16±3) ml/kg/min. Key findings included profound metabolic inflexibility (high resting and recovery RER) and delayed heart rate recovery, indicative of autonomic dysfunction.

Conclusion: This case series highlights a triad of physiological impairments including reduced cardiovascular reserve, metabolic inflexibility, and autonomic dysfunction that contribute to severe exercise intolerance in obese postmenopausal women. These findings support the clinical value of CPET for identifying individual-specific physiological limitations and guiding personalized exercise interventions in this high-risk population.

Key words: obesity, postmenopausal women, incremental exercise testing, cardiopulmonary exercise testing, metabolic response, respiratory exchange ratio

Introduction

Obesity prevalence has increased dramatically worldwide (World Health Organization Obesity and Overweight, 2025) and is recognized as a chronic relapsing disease (Bray et al., 2017). Excess adiposity is a major independent

risk factor for type 2 diabetes, cardiovascular disease, and metabolic syndrome (Calle & Kaaks, 2004; Haslam & James, 2005; Lavie et al., 2009). These effects arise from complex interactions of genetics, diet, and lifestyle (Bray et al., 2017; Hill et al., 2012) and are perpetuated by low-grade inflammation and altered gut microbiota in obesity (Hotamisligil, 2006; Turnbaugh et al., 2009). Effective management requires a multifactorial approach: dietary energy balance (Hall et al., 2011), regular physical activity (Donnelly et al., 2009; Swift et al., 2014), and weight-loss maintenance (Jakicic et al., 2018) are all essential. Indeed, current guidelines emphasize integrated lifestyle interventions for weight control (Hruby & Hu, 2015). Because postmenopause brings a decline in estrogen, increased visceral fat, and worsening insulin resistance, these factors synergistically impair cardiometabolic function in middle-aged and postmenopausal women with obesity (Després, 2012; Lavie et al., 2009). In addition to these metabolic changes, postmenopausal women with obesity commonly exhibit reduced cardiorespiratory fitness, impaired substrate utilization during exercise, and altered autonomic regulation, which together contribute to marked exercise intolerance and elevated cardiovascular risk (Monferrer-Marín et al., 2024; Vasconcelos et al., 2025).

Incremental cardiopulmonary exercise testing (CPET) can unmask early maladaptations in this group, such as a disproportionate rise in ventilatory drive or early anaerobic shift. Importantly, CPET provides an integrated assessment of cardiovascular reserve, metabolic flexibility, and autonomic recovery responses, enabling identification of the dominant physiological limitations to exercise in individual patients (Woodward et al., 2025; Sánchez-Delgado et al., 2023).

In this case series, we evaluated the cardiorespiratory and metabolic responses during graded cycle ergometry in nine obese postmenopausal women, to characterize the magnitude and nature of their exercise intolerance. While cohort studies have established low mean fitness in this population, the specific patterns of physiological limitation and the degree of inter-individual variability remain poorly characterized. Therefore, the purpose of this case series was to provide a detailed characterization of the cardiorespiratory and metabolic responses during incremental exercise in nine obese postmenopausal women, with particular emphasis on the interaction between cardiovascular reserve, metabolic flexibility, and autonomic function as determinants of exercise intolerance.

Methods

Participants

A total of nine postmenopausal women (mean age 56.78±9.02 years) clinically diagnosed with obesity (BMI≥30 kg/m²) were enrolled in this study (World Health Organization Obesity and Overweight, 2025). Inclusion criteria required participants to be sedentary (no regular exercise for at least six months) and within an age range of 44 to 69 years. Participants were free of overt cardiovascular or pulmonary disease as determined by a clinical evaluation and medical history. Standard exclusion criteria were applied, including orthopedic or neuromuscular conditions that would contraindicate exercise and the use of any medications known to alter energy metabolism. Before testing, all participants underwent a physical examination and provided written informed consent. The study was conducted in accordance with institutional ethical standards and received approval from the institutional ethics committee. Anthropometric measurements, including age, body weight, height, and BMI were recorded. Body surface area (BSA) was calculated using the Du Bois & Du Bois formula (Du Bois & Du Bois, 1989). Baseline vital signs were recorded after 3 minutes of seated rest. This case series was prepared and reported in accordance with the CARE guidelines (Gagnier et al., 2013).

Exercise protocol and measurements

Participants completed an incremental exercise test to exhaustion on a programmable cycle ergometer (Marquette, Ergocomp EL 1200 – USA). The protocol began with a seated rest period, followed by a workload that increased continuously by 20 watts per minute. The test was terminated when a participant could no longer maintain a steady pedaling rate of at least 50 rpm; this point was recorded as the maximum workload (W_{max}), a functional indicator of the participant's exercise capacity.

Throughout the test, respiratory gases were analyzed breath-by-breath using a mass spectrometer (II-CPX Express, Medgraphics, USA) to determine oxygen consumption (VO_2) and carbon dioxide production (VCO_2), fundamental parameters for assessing metabolic efficiency and ventilatory response to exercise.

Beat-by-beat heart rate (HR) was continuously monitored using a chest strap monitor (Polar, Italy), synchronized with the metabolic analysis system for the assessment of cardiovascular response during exercise.

From these direct measurements, the following variables were calculated:

- **Respiratory exchange ratio (RER):** This was calculated as the ratio of VCO_2/VO_2. RER is an indicator of the type of energy substrate used and the predominance of aerobic or anaerobic metabolism.
- **Anaerobic threshold (AT):** This was identified at the workload where the RER value first reached 1.00 (Liguori & Medicine, 2022), which corresponds to increased lactate production and activation of anaerobic metabolism, with a consequent increase in perceived effort.
- **Oxygen pulse (O2 Pulse):** This was calculated as the ratio of VO_2/HR, serving as an indirect index of cardiac efficiency and stroke volume.

The sequence of study procedures, from participant recruitment to data analysis, is summarized in Figure 1.

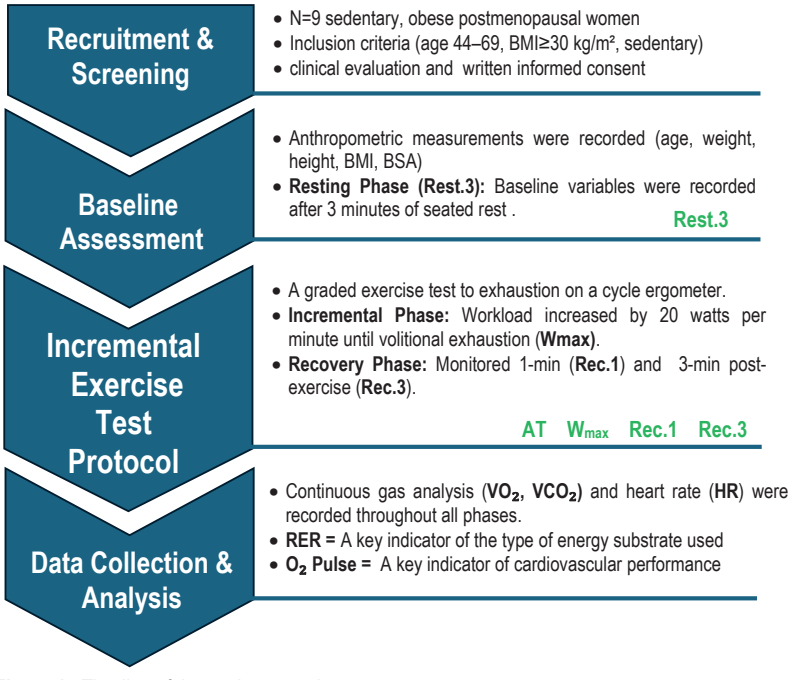


Figure 1. Timeline of the study protocol.

Statistical analysis

Data were analyzed to yield mean, standard deviation (SD), and range to describe the central tendency and dispersion of responses across the group. The primary analysis is focused on the descriptive presentation of individual and group physiological trajectories. All results are presented as mean±SD unless otherwise specified.

Case presentation

Participant characteristics

The characteristics of the nine participants are detailed in Table 1. The group had a mean age of 56.78±9.02 years and a mean BMI of 33.87±3.80 kg/m², classifying them as obese. Maximal exercise capacity was severely limited across the group, with a mean VO_{2max} of 16±3 ml/kg/min and a mean W_{max} of 111±24 W.

Table 1. Participant characteristics and peak exercise performance

Subject	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m²)	BSA (m²)	AT (W)	Wmax (W)
1	66	82	161	36,4	1,77	60	100
2	59	81	150	34,6	1,78	60	100
3	61	71	153	29,6	1,70	80	100
4	69	84	155	34,8	1,83	40	80
5	52	83	155	32,8	1,85	80	140
6	44	70	159	29,1	1,69	60	120
7	64	78	155	29,7	1,83	40	80
8	47	106	162	37,6	2,14	40	140
9	49	104	168	37,3	2,11	80	140
Mean	56.8	84.3	157.6	33,55	1,86	60.0	111.1
SD	9.0	12.7	5.5	3,39	0,16	17.3	24.7

Age, body weight, and anthropometric indexes are shown with means±SD. AT: Anaerobic threshold, W_{max}: Maximum workload, BSA: Body surface area, BMI: Body mass index.

Metabolic and gas exchange responses

The physiological responses to the incremental exercise test are summarized in Table 2 and Figure 2. Significant changes were observed across the five experimental phases. From Rest.3 to peak exercise, there were significant increases in HR, VO_2, VCO_2, and O_2 Pulse (all $p<0.001$). During recovery, HR and VCO_2 remained significantly elevated above baseline at Rec.3 ($p<0.0001$), while VO_2 also remained slightly elevated ($p<0.002$). The mean power output achieved at the AT was 60±17 W, which corresponded to 54% of the mean maximal workload (W_{max}) of 111±24 W (Table 2).

The mean heart rate (HR) increased from 69±17 bpm at Rest.3 to 143±16 bpm at Wmax. At Rec.1 and Rec.3, HR was 125±22 bpm and 92±18 bpm, respectively. There was a significant difference between HR at Rest.3 and Rec.3 ($p<0.0001$) (Table 2). VO_{2max} increased from 4±1 at Rest.3 to 12±2 at AT and 16±3 at W_{max}. Although workload increased ~50% from AT to Wmax, VO_2 increased only modestly beyond that point. The decline of VO_2 in recovery was slow, remained ~27% above baseline at Rec.3 ($p<0.002$).

Carbon dioxide production (VCO_2) increased from a mean of 263±11 ml/min at Rest.3 to 1558±347 ml/min at Wmax. At Rec.3, the mean VCO_2 was 516±97 ml/min, representing a 96% increase above resting levels ($p<0.0001$; Table 2). The mean RER was 0.93±0.05 at Rest.3, 1.15±0.06 at Wmax, and 1.38±0.15 at Rec.3 (Table 2).

The oxygen pulse (VO_2/HR) increased from 4.4±1.0 ml/beat at Rest.3 to a peak of 9.5±2.1 ml/beat at W_{max}, before returning to 4.2±1.0 ml/beat after Rec.3, with no statistically significant changes ($p>0.05$; Table 2).

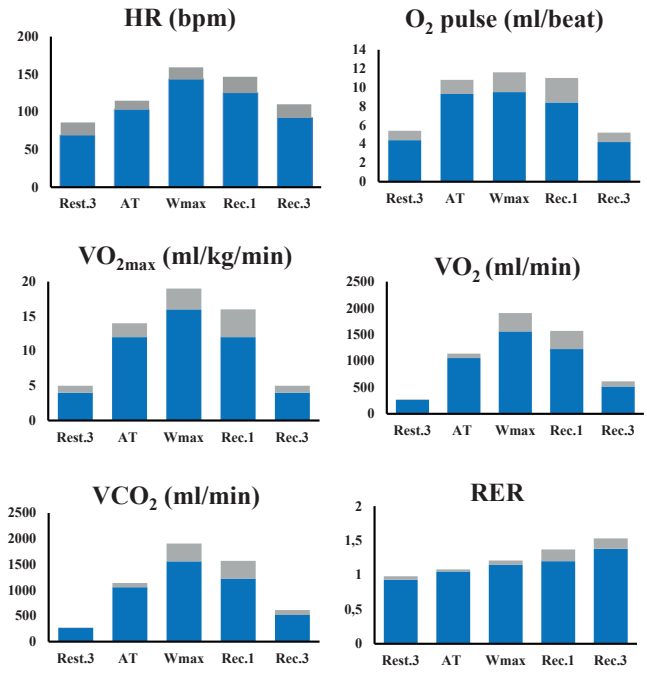
Table 2. Cardiorespiratory and metabolic responses at five stages of the exercise test

Phase	REST.3	AT	Wmax	REC.1	REC.3
HR (bpm)	69±17	103±11.9	143±16.1	125±21.6	92±18.1
VO_{2max} (ml/kg/min)	4±1	12±2	16±3	12±4	4±1
VO_2 (ml/min)	295±25	1004±75	1343±234	1018±266	374±56
VCO_2 (ml/min)	263±11	1055±8	1558±347	1224±344	516±97
RER	0.93±0.05	1.05±0.03	1.15±0.06	1.20±0.17	1.38±0.15
O_2 Pulse (ml/beat)	4.4±1.0	9.3±1.5	9.5±2.1	8.4±2.6	4.2±1.0

Rest.3: rest, AT: Anaerobic threshold, W_{max}: Maximum workload, Rec.1: 1-min recovery, Rec.3: 3-min recovery

Summary of group responses

As shown in Figure 2, while all participants demonstrated severe deconditioning, considerable heterogeneity was observed in their metabolic and autonomic responses. For instance, RER during the recovery period ranged from 1.25 to 1.50. Similarly, the rate of heart rate decline in recovery varied substantially among individuals (Figure 2).



Rest.3: rest, AT: Anaerobic threshold, Wmax: Maximum workload, Rec.1: 1-min recovery, Rec.3: 3-min recovery

Figure 2. Cardiorespiratory and metabolic responses to incremental exercise.

Discussion

This case series demonstrates that obese postmenopausal women have profoundly impaired exercise physiology. All key parameters (VO_2max, workload, chronotropic reserve) were well below reference values for sedentary peers, reflecting the synergistic negative effects of obesity, aging, and menopause (Després, 2012; Lavie et al., 2009).

The findings can be explained by a triad of factors:

(1) **Reduced cardiovascular reserve:** Lower maximal stroke volume and chronotropic response (peak HR ~143 bpm vs. 220–age) limit cardiac output.

(2) **Impaired peripheral oxygen utilization:** Likely due to diminished mitochondrial density/function in muscle (Larsen et al., 2011) coupled with a predominance of glycolytic (type II) fibers (Andersen & Henriksson, 1977), causing rapid lactate accumulation.

(3) **Chronic sympathetic overactivity:** Excess adiposity and menopause-related hormonal shifts sustain a higher resting metabolic rate (evidenced by high resting RER) and delay recovery.

Together, these produce the marked deconditioning observed.

The mean VO_2max of 16±3 ml/kg/min is alarmingly low – far under the ~22 ml/kg/min threshold considered necessary for basic functional independence in older women (Liguori & Medicine, 2022) and is a strong independent predictor of cardiovascular morbidity and all-cause mortality.

Peak workload (111±24 W) was ~30–40% lower than normative values for sedentary women, underlining a severe loss of integrated heart–lung–muscle efficiency (Larsen et al., 2011). Post-exercise VO_2 fell slowly, indicating prolonged oxygen debt and inefficient aerobic recovery, a pattern linked to reduced mitochondrial density and impaired lactate clearance (Larsen et al., 2011).

The early anaerobic shift is evidenced by RER behavior. Resting RER was ~0.93, suggesting high baseline glycolysis. In recovery, it soared to 1.38, indicating heavy metabolic acidosis driving compensatory hyperventilation to expel excess CO_2. This pattern reveals impaired metabolic flexibility and implies that even modest exercise provokes major acid-base disturbances (Brooks, 1986).

Importantly, the O_2 Pulse was maintained at expected levels (Crisafulli et al., 2007). This is a critical clinical finding, as it suggests that the heart's intrinsic contractile function was preserved and helps to rule out primary cardiac disease as the cause of exercise intolerance. The limitation is therefore due to central and peripheral deconditioning (low stroke volume and poor tissue O_2 extraction) (Crisafulli et al., 2007; Larsen et al., 2011). The blunted HR response and delayed HR recovery further highlight autonomic nervous system dysfunction, a known prognostic marker for increased cardiovascular risk (Cole et al., 1999; Haddock et al., 1998).

Our observations are in line with prior reports. For instance, Hulens et al. (2001) found that obese subjects use a greater fraction of their VO_2max at AT, significantly reducing their aerobic reserve (Hulens et al., 2001). Despite not including a control group, the relative intensities here (AT at 54% Wmax) mirror those findings, showing that these individuals operate closer to their physiological limits even during moderate effort, leading to early fatigue.

Clinically, these data underscore the need for tailored interventions. Our findings emphasize that a simple measure of peak VO_2 alone is insufficient. The abnormal RER kinetics observed in several of our cases point to an underlying metabolic inflexibility missed by standard exercise tests. We therefore recommend that comprehensive CPET with full gas exchange analysis be considered for risk stratification in this population. Beyond weight management, the goal is to address the compounding physiological deficits of aging and menopause, such as

the decline in mitochondrial function exacerbated by estrogen loss. In line with the guidelines of the ACSM and the American Heart Association (Lavie et al., 2015), progressive aerobic training (starting ~40–50% of VO_2max) and resistance training should be prescribed as a form of physiological therapy (Westcott, 2012) to increase mitochondrial biogenesis (Larsen et al., 2011), shift muscle fiber phenotype toward more oxidative types (Andersen & Henriksson, 1977), and raise the lactate threshold. Nutritional strategies (caloric deficit, anti-inflammatory diet) are equally important to reduce visceral fat and improve metabolic profile (Hruby & Hu, 2015; Lavie et al., 2009). Together, these central strategies can increase stroke volume and O_2 extraction, breaking the vicious cycle of sedentary behavior, obesity, and functional decline.

Furthermore, only through comprehensive, multidisciplinary management can long-term adherence be encouraged, patient empowerment be promoted, and sustainable clinical outcomes be achieved. These results strongly support prescribing structured aerobic and resistance training as physiological therapy to restore metabolic flexibility, improve mitochondrial function, and enhance quality of life (Lavie et al., 2015; Liguori & Medicine, 2022). Early recognition of this cardiometabolic drift can prompt interventions to prevent further decline and reduce long-term cardiovascular risk.

Limitations

This study is limited by its small sample (n=9), which restricts statistical power and generalizability. No lean control group or mechanistic biomarkers (e.g. lactate levels, inflammatory markers) were measured. Furthermore, we did not collect detailed data on comorbidities or medications that could have influenced the results. However, the detailed gas-exchange and HR data provide a strong pathophysiological basis. Future studies should involve larger cohorts, include biochemical and inflammatory markers, and track longitudinal responses to interventions to define clear operational guidelines for this population.

Conclusion

In conclusion, this case series provides a detailed physiological portrait of severe deconditioning in obese postmenopausal women, characterized by a triad of reduced cardiovascular reserve, metabolic inflexibility, and autonomic dysfunction. Peak VO_2, W_{max}, and chronotropic response were all markedly reduced, while RER and VCO_2 remained abnormally high into recovery. The significant inter-individual variability highlights the value of comprehensive CPET in unmasking the specific pathophysiological drivers of exercise intolerance to guide personalized interventions. Therefore, these findings emphasize that comprehensive CPET, including assessment of aerobic capacity and autonomic recovery, should be an integral part of clinical monitoring to identify at-risk individuals and implement timely preventive strategies.

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PROFILE OF MUSCULAR STRENGTH, ENDURANCE, AND MOVEMENT PATTERNS IN RECREATIONAL INDIVIDUALS PERFORMING TARGETED STRENGTH TRAINING

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Abstract This study aimed to assess muscular strength, endurance, and movement pattern quality in adults engaged in recreational, targeted strength training compared to physically active individuals without a specific strength focus. A total of 60 participants were included: 34 in the experimental group (17 men, 17 women) and 26 in the control group (13 men, 13 women). All subjects completed the Functional Movement Screen (FMS) to evaluate movement quality. Muscular strength and endurance were assessed using four tests based on ACSM's Guidelines for Exercise Testing and Prescription (11th ed.): Handgrip Strength, Bench Press Ratio, Leg Press Ratio, and Push-Up Test. In the strength-training group, 79.4% scored ≥18 on the FMS (vs 61.5% in controls), with no scores <14 (vs 3.8%). In the Handgrip Test, 63% scored at or above the 50th percentile (vs 58%). The experimental group more often achieved "Good" or higher classifications in the bench press and push-up tests. Notably, 45% scored "Very Good" or "Excellent" in push-ups (vs 19% in controls). Findings suggest that regular, targeted strength training contributes to higher levels of muscular strength, endurance, and movement quality, potentially reducing injury risk and enhancing functional performance.

Key words: functional fitness, strength training, Functional Movement Screen, muscle strength, muscle endurance

Introduction

Muscular strength and endurance constitute key components of physical fitness and are essential indicators of human health and functionality (ACSM, 2021). From a physiological perspective, muscular strength is defined as the ability of a muscle or muscle group to exert maximal force against resistance in a single contraction (Kenney et al., 2019). It can be assessed under static (isometric) or dynamic (concentric–eccentric) conditions using tests such as the one-repetition maximum (1-RM) or the Handgrip Strength Test. Muscular endurance, in contrast, refers

to the ability of muscles to perform repeated contractions or sustain a given level of tension over time without loss of movement quality (Schoenfeld et al., 2016).

Regular physical activity, particularly resistance training, induces a range of physiological adaptations leading to increases in strength, endurance, postural stability, and overall functional fitness (Górski, 2019; Plowman & Smith, 2014). Recent research confirms that even in recreationally trained individuals, systematic resistance training produces significant neuromotor adaptations and improvements in Functional Movement Screen (FMS) scores, particularly in the domains of stability and movement control (İribalcı et al., 2024).

Functional fitness is defined as the ability to perform daily tasks efficiently, safely, and independently (Gieroba, 2019). The literature indicates that resistance training is a crucial element in injury prevention, quality-of-life improvement, and the maintenance of functional capacity across age groups (ACSM, 2021; Schoenfeld et al., 2017). One of the most recognized tools for assessing movement quality and identifying functional deficits is the Functional Movement Screen (FMS). It consists of seven movement tasks that evaluate mobility, stability, and neuromuscular coordination, and is widely used to assess injury risk and movement pattern quality (Cook et al., 2014).

Studies have shown that regular resistance and stabilization training can improve FMS scores, particularly when programs include complex functional movements engaging the core musculature (Behm et al., 2010; Okada et al., 2011). Similarly, Wang et al. (2024) demonstrated that functional resistance training significantly enhances not only muscular strength but also movement quality measured by FMS among wushu athletes, underscoring the universality of the FMS tool across active populations.

The practical application of the FMS test was presented in the study "The Effects of Strength and Conditioning on Functional Movement Screen™ Scores in Secondary School Basketball" (Dexter et al., 2020), where significant improvements in FMS performance were observed among young basketball players following a structured strength and conditioning program. These findings confirm the FMS test's utility for monitoring functional changes in physically active populations.

The present study utilized four muscular strength and endurance tests (Handgrip Strength Test, Bench Press Weight Ratio, Leg Press Weight Ratio, and Push-Up Test), following the guidelines of the American College of Sports Medicine (ACSM, 2021). The ACSM is a globally recognized authority in exercise science and sports medicine, known for developing evidence-based standards and protocols. Since its founding in 1954, the organization has regularly published and updated guidelines for assessing physical fitness, covering key components such as cardiorespiratory endurance, muscular strength, muscular endurance, and flexibility. These recommendations are widely applied in sports medicine and physiotherapy practice.

A practical example of these standards is the study "Development of a Standard Push-up Scale for College-Aged Females" (Lang et al., 2022), which established normative data for the push-up test among university-aged women based on ACSM recommendations. The results confirmed the diagnostic value of simple field tests for assessing muscular endurance and functional fitness.

Comparable findings were reported by Yilmaz et al. (2024), who compared recreationally active and sedentary individuals, confirming a significant association between regular exercise participation, higher FMS scores, and improved relative strength parameters.

Previous analyses indicate that resistance training leads to favorable neuromuscular adaptations by enhancing motor unit recruitment efficiency and the ability to generate force (Suchomel et al., 2018). Most research on these phenomena, however, has focused on elite athletes or clinical populations, with relatively few studies addressing

recreationally trained adults—among whom significant strength-endurance and functional adaptations also occur (Peterson et al., 2011). This research gap has been highlighted in recent publications (İribalcı et al., 2024; Yilmaz et al., 2024), which emphasize the need for integrated assessment of strength, endurance, and movement quality in recreationally active adults. This gap limits understanding of how resistance training affects comprehensive movement performance in this population. The originality of the present study lies in its integrated diagnostic approach combining the assessment of muscular strength, endurance, and movement quality (FMS) within a single population. This design enables simultaneous analysis of strength-endurance and functional components, allowing for a more complete evaluation of recreational training effects. In the context of contemporary sports medicine and exercise physiology, a holistic approach to analyzing strength, endurance, and movement functionality is a key aspect of assessing training effectiveness, planning injury prevention strategies, and individualizing exercise programs (ACSM, 2021; Suchomel et al., 2018). Therefore, the aim of the present study was to conduct a comprehensive evaluation of muscular strength, endurance, and functional fitness in adults regularly participating in resistance training compared with those engaged in general physical activity not focused on strength development.

Methods

A total of 60 participants took part in the study, including 34 individuals in the experimental group (EG) and 26 in the control group (CG). Both groups maintained an equal gender distribution (50% women, 50% men). Participants' ages ranged from 18 to 40 years (M=24.3; SD=4.8). The majority of participants held a higher education degree (over 50% in both groups) and resided in large urban areas with populations exceeding 500,000 inhabitants (approximately 77%). Relationship status was evenly distributed, with similar proportions of single and partnered individuals.

The study was conducted in compliance with the Declaration of Helsinki and was approved by the Bioethics Committee of the Karol Marcinkowski Medical University, Poznań, Poland (No.163/125).

All participants met the inclusion criteria: they were healthy adults without contraindications to physical exercise and reported no injuries within the previous six months. Each participant engaged in regular physical activity 3–4 times per week, with training sessions lasting between 1 and 2 hours.

Exclusion criteria included: the use of medications affecting the nervous or muscular system, metabolic disorders, and a lack of prior training experience. The experimental group (EG) consisted of individuals who had been consistently engaged in strength training for at least 12 months (3–4 sessions per week, each lasting 60–90 minutes). The control group (CG) included participants who practiced other forms of recreational physical activity, such as swimming, cycling, yoga, Pilates, or brisk walking – with the same frequency and duration. Demographic and lifestyle data were collected using a custom-designed questionnaire containing standard sociodemographic items to characterize the participants. A detailed summary of participant characteristics is presented in Table 1.

Table 1. Characteristics of the Experimental and Control Groups

	Experimental group n (%)	Control group n (%)
Sex		
– Men	17 (50%)	13 (50%)
– Women	17 (50%)	13 (50%)
Age		
– 18–26 years old	17 (50%)	11 (42.3%)
– 27–35 years old	7 (20.6%)	6 (23.1%)
– >35 years old	10 (29.4%)	9 (34.6%)
Education		
– Higher education	22 (64.7%)	15 (57.7%)
– Secondary education	9 (26.5%)	6 (23.1%)
– Vocational education	3 (8.8%)	5 (19.2%)
Place of residence		
– City >500,000 inhabitants	26 (76.5%)	20 (76.9%)
– City 50,000–100,000 inhabitants	6 (17.6%)	–
– Village	2 (5.9%)	6 (23.1%)
Relationship status		
– Single	17 (50%)	9 (34.6%)
– In a relationship	17 (50%)	17 (65.4%)
Number of training sessions per week	3–4: 34 (100%)	3–4: 26 (100%)
Duration of a single training session	1–2 hours: 34 (100%)	1–2 hours: 26 (100%)

The study was conducted in July and August 2024 at the Fitness Point Training Center in Poznań, Poland, which was equipped with professional resistance training facilities. Participants were informed about the study procedures and were instructed to refrain from strenuous exercise, caffeine, and alcohol consumption for 24 hours prior to testing.

Before testing, each participant attended a familiarization session to become acquainted with the maximal strength (1-RM) and FMS testing procedures. On the test day, all participants performed a standardized warm-up, consisting of 5 minutes of ergometer cycling, 5 minutes of dynamic stretching, and three sets of light-load exercises.

The order of tests was identical for all participants:

a) Functional Movement Screen (FMS)
b) Handgrip Strength Test
c) Bench Press Weight Ratio
d) Leg Press Weight Ratio
e) Push-Up Test
f) Rest intervals between tests ranged from 5 to 10 minutes, and between attempts within a single test, 2 to 3 minutes. All measurements were performed by the same examiner — a certified strength and conditioning specialist.
g) Resistance training program followed by participants in the EG group was performed 3–4 times per week for a minimum of 12 months, following the principles of progressive overload (Suchomel et al., 2018; Schoenfeld et al., 2021). The training program included 6–8 multi-joint exercises targeting major muscle groups (e.g., squat, deadlift, bench press, bent-over row, overhead press, pull-up), performed in 3–5 sets of 6–12 repetitions at 65–85% of 1-RM. Rest intervals between sets were 60–120 seconds. The program

followed an undulating periodization model, with cyclical adjustments in training volume and intensity every 4–6 weeks. The goal of the program was to develop maximal strength and muscular endurance, without specific preparation for competitive performance. The control group (CG) did not participate in resistance training and engaged only in recreational and health-oriented physical activities, such as swimming, cycling, yoga, Pilates, or brisk walking, with similar frequency and duration.

The testing protocol included the following components:

a) Functional Movement Screen (FMS):

The FMS consisted of seven movement tasks: deep squat, hurdle step, in-line lunge, shoulder mobility, active straight-leg raise, trunk stability push-up, and rotary stability. Each task was scored on a 0–3 scale (Cook et al., 2014). Score interpretation:

- 18–21 points – low injury risk
- 14–17 points – moderate risk (25–35%)
- <14 points – high risk (up to 50%)

b) Handgrip Strength Test:

The test was conducted according to ACSM (2021) guidelines. Isometric grip strength was measured using a calibrated hand dynamometer. Participants performed three trials for each hand while seated, with the elbow flexed at 90° and without arm support. The highest value was recorded for analysis.

c) Bench Press Weight Ratio:

Maximal upper-body strength was assessed using the actual 1-RM method following ACSM (2021) recommendations. The load was progressively increased by 2.5–5% of body mass until technical failure occurred. The result was expressed as the ratio of lifted weight to body mass.

d) Leg Press Weight Ratio:

The test was conducted according to ACSM (2021) procedures using a Technogym 45° Leg Press machine. The maximum single-repetition load was determined, and results were expressed as the ratio of lifted weight to body mass.

e) Push-Up Test:

The test followed ACSM (2021) standards. Participants performed the maximum number of push-ups at a tempo of 40 beats per minute, paced by a metronome. The test was terminated when the participant failed to maintain full elbow extension or lost rhythm. The outcome was the number of correctly performed repetitions.

Data Analysis

Upon completion of all testing procedures, the collected data were carefully recorded and anonymized. Descriptive statistics were calculated, including arithmetic means, standard deviations, and score ranges. To evaluate differences between the experimental and control groups, independent samples t-tests were applied, with the level of statistical significance set at $p<0.05$. All statistical analyses were performed using the Statistica software package.

Results

The mean total Functional Movement Screen (FMS) score was 18.71±2.27 points in the experimental group and 18.58±3.61 points in the control group. Median and mode values were similar to the means, and the range

of scores spanned 14–21 points. The coefficient of variation (Vr) indicated moderate within-group variability (Vr_EG=12.1%; Vr_CG=19.4%). The vast majority of participants achieved a score of ≥18 points, indicating a low risk of injury (EG: men 76%, women 82%; CG: men 69%, women 54%). In the control group, a score below 14 points was observed in only one participant (8%).

No statistically significant differences between groups were found (t(58)=0.16;=0.87), and the Cohen's d=0.04 indicated a negligible effect size. The two-way ANOVA (2×2: group × sex) revealed no significant interaction effects (F(1,56)=0.44; p=0.51), indicating that the quality of movement patterns did not differ significantly between groups or across sexes.

In the analysis of individual FMS components, slightly higher mean scores were recorded in the experimental group for FMS1 (deep squat), FMS3 (in-line lunge), and FMS5 (active straight leg raise). However, none of these differences reached statistical significance. Detailed results are presented in Table 2.

Table 2. Results of the Functional Movement Screen (FMS) Test

Score range	EG Men n (%)	EG Women n (%)	CG Men n (%)	CG Women n (%)
<14 pkt	0 (0%)	0 (0%)	1 (8%)	0 (0%)
14–17 pkt	4 (24%)	3 (18%)	3 (23%)	6 (46%)
≥18 pkt	13 (76%)	14 (82%)	9 (69%)	7 (54%)

Table 3 presents the average values obtained in the strength and endurance tests.

Table 3. Results of Strength and Endurance Tests

Test	EG (M±SD)	CG (M±SD)	Cohen's d	p
Handgrip [kg]	39,56±12,76	37,81±8,56	0,16	0,41
Bench Press Ratio	0,905±0,117	0,848±0,116	0,49	0,09
Leg Press Ratio	1,70±0,12	1,61±0,12	0,75	0,06
Push-Up [n]	20,97±12,92	14,50±6,87	0,60	<0,05

The medians and modes for all tests were close to the mean values, confirming the normality of distributions. The observed value ranges were as follows:

a) Handgrip Strength: 21–60 kg
b) Bench Press Ratio: 0.68–1.08
c) Leg Press Ratio: 1.45–1.85
d) Push-Up Test: 5–45 repetitions
e) The coefficients of variation (Vr) indicated greater individual variability in endurance tests (Push-Up: Vr=61.6%) than in relative strength tests (Vr=7–14%). A statistically significant difference between groups was observed only in the Push-Up Test (p<0.05), with a moderate effect size (d=0.60). This result confirms the superiority of the experimental group in upper-body muscular endurance. In the Bench Press and Leg Press tests, tendencies favoring the experimental group were also noted (d=0.49–0.75), although these did not reach statistical significance – likely due to the moderate sample size and within-group variability. The two-way ANOVA (group × sex) revealed a significant main effect of group for the Push-Up Test (F(1,56)=5.12; p=0.027), whereas neither sex effects nor interaction effects were found (p>0.05).

f) A Pearson correlation analysis was performed between the total FMS score and the strength and endurance tests (Handgrip, Bench Press, Leg Press, Push-Up). No statistically significant correlations were observed ($p>0.05$), although weak positive trends were identified — the strongest association occurred between FMS and Push-Up ($r=0.28$; $p=0.07$). This result suggests that better movement pattern quality may co-occur with greater muscular endurance, although it does not directly indicate maximal strength capacity. For the main variables (FMS, Bench Press Ratio, Leg Press Ratio, Push-Up Test), a post-hoc power analysis was conducted using G*Power 3.1.9.7 (Faul et al., 2009), assuming a medium effect size ($d=0.5$, $\alpha=0.05$, $n=60$). The obtained statistical power ($1-\beta$) was 0.83, indicating sufficient sensitivity of the tests and confirming the reliability of observed differences between groups.

Summary of findings:

a) FMS: No significant differences between groups; most participants demonstrated proper movement patterns (≥18 points).
b) Strength and endurance: Significant advantage of the experimental group in the Push-Up Test ($p<0.05$; $d=0.60$). Other differences were non-significant but favored EG.
c) ANOVA: Confirmed a significant main effect of group ($p<0.05$) without group × sex interaction.
d) Correlations: No significant associations between FMS and strength tests; the strongest trend was observed between FMS and Push-Up.
e) Power analysis: The obtained value of power=0.83 indicates adequate statistical sensitivity for the conducted analyses.

Discussion

The purpose of this study was to assess the levels of muscular strength, endurance, and movement pattern quality among adults engaged in structured strength training compared with physically active individuals not specifically focused on strength development. In line with the findings of Cook et al. (2014) and the principles of functional movement progression described by Zatsiorsky (2006), a well-designed resistance training program does not deteriorate movement quality.

The results of the present study confirm this assumption — despite higher training loads, the experimental group maintained a high level of movement quality as assessed by the Functional Movement Screen (FMS). The absence of significant differences between groups in FMS scores may suggest that regular physical activity — regardless of its form — contributes to maintaining effective motor control and movement stability. This observation aligns with findings reported by Fitton-Davies et al. (2022) and Dexter et al. (2020), who demonstrated that both resistance training and general recreational activity can enhance movement patterns and reduce asymmetries. Furthermore, Wang et al. (2025), in a randomized controlled trial, showed that long-term strength and functional training significantly improves motor control and trunk stability, which provides strong empirical support for the findings of the present study.

The analysis of strength tests revealed a superiority of the experimental group in upper-body muscular endurance (Push-Up Test). This finding corroborates previous evidence by Schoenfeld et al. (2016) and Suchomel et al. (2018), indicating that systematic resistance training leads to increases in both maximal strength and local muscular endurance. The underlying mechanisms include enhanced motor unit recruitment, improved contraction synchronization, and metabolic adaptations that increase resistance to fatigue (Zatsiorsky, 2006; Bompa &

Buzzichelli, 2022). Similar tendencies were observed by Maleki et al. (2025), who, in a meta-analysis, found that interventions combining strength and stabilization training significantly improve FMS scores, regardless of participants' training background. It is also worth noting that training adaptations in strength outcomes may differ between sexes — women typically show smaller gains in absolute strength but similar improvements in relative strength (Bishop et al., 2008; Roberts et al., 2020). Likewise, Khuyagbaatar et al. (2025) reported that prior resistance training experience is strongly correlated with movement quality and reduced overload risk, supporting the trends observed in the present study. However, the applied ANOVA analysis did not reveal significant group × sex interactions, which might be due to insufficient statistical power to capture subtle sex-related differences.

When interpreting the FMS outcomes, it should be emphasized that the absence of group differences does not imply a lack of training effect, but rather confirms that various forms of regular physical activity can yield comparable levels of motor competence when performed with proper technique. This interpretation aligns with earlier studies (Teyhen et al., 2012; Kiesel et al., 2007), which indicated that general physical activity and stabilization exercises are sufficient to maintain appropriate movement patterns in adults.

Several limitations should be considered when interpreting the results. The sample size was moderate (n=60), potentially reducing the statistical power to detect small group or sex differences. The study design was cross-sectional, precluding causal inferences about the relationship between training and changes in movement quality. The lack of randomization and absence of longitudinal follow-up limit the ability to assess the durability of observed effects.

Finally, no real injury data were collected, which prevents a direct conclusion that resistance training reduces injury risk – this should instead be interpreted as a potential preventive effect, requiring further prospective studies. Recent publications (Wang et al., 2025; Khuyagbaatar et al., 2025) also emphasize the necessity of such prospective research, particularly among recreationally active adult populations. Practical conclusions:

a) regular resistance training may enhance upper-body muscular endurance and help maintain high-quality movement patterns;
b) the absence of significant FMS differences between groups suggests that various forms of physical activity can effectively maintain functional mobility and stability;
c) the findings highlight the importance of balancing strength and functional training components in recreational and health-oriented programs;
d) the use of the FMS in evaluating physically active adults may serve as a useful tool for monitoring movement quality and identifying potential overload risks;
e) for coaches and physiotherapists, these results may support the individualization of training loads while maintaining an emphasis on safety and movement quality;
f) future research should increase sample size, apply randomized participant selection, and include prospective observation to confirm the long-term effects of resistance training on injury risk and functional adaptations.

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"TALKING ABOUT PENCAK SILAT TRAINING INNOVATION": COACHES' EFFORTS TO IMPROVE EXERCISE BEHAVIOR AND TECHNICAL PERFORMANCE AMONG YOUNG ATHLETES WITH AUGMENTED REALITY

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Abstract This study aims to investigate the effects of augmented reality training (ART) towards exercise behavior, and technical performance among young athletes. A 9-week experiment was adopted in this study. Fifty young male Pencak Silat athletes were involved as participants, and they were assigned into ART (n=25), and control (n=25) groups. Measurements of exercise behavior (exercise intensity, exercise time, exercise frequency), and technical performance (target punching test, target kick test) were conducted at pre-, mid-, and post-intervention. This study generated two main research findings. First, there were significant effects interaction of condition vs. time (p=0.001), condition (p=0.019), and time (p<0.001) on the exercise behavior variable in the exercise intensity indicator. At the same time, we observed the effects of the interaction of condition vs. time (p=0.015), condition (p=0.023), and time (p<0.001) in the exercise time indicator, while the exercise frequency indicator showed the effects of interaction of condition vs. time (p<0.001), condition (p=0.005), and time (p<0.001). Second, there was a significant effect on interaction of condition vs. time (p<0.001), condition (p=0.001), and time (p<0.001) on the technical performance variable in the target punching test indicator. The target kick test indicator showed the effects interaction of condition vs. time (p<0.001), condition (p=0.001), and time (p<0.001). Post-hoc analysis showed that the ART group has higher score than the TT group in terms of increasing exercise behavior and technical performance. The conclusion is that the 9-week ART program has proven effective in improving aspects of exercise behavior and technical performance among young Pencak Silat athletes.

Key words: technology-based training, habitual behavior, competitive performances, combat sports

Introductions

In recent decades, training methodologies for combat sports has shown significant progress by involving the application of modern technology (Lygouras & Tsinakos, 2024; Witkowski et al., 2017). Previous studies involved trainers in combat sports with virtual reality (Ritter et al., 2022; Witte et al., 2022), or augmented reality (Usra et al., 2024). Pencak Silat is one type of combat sport that is popular in Asian countries. In addition, similar to other combat sports (e.g., Karate, Taekwondo, Judo, Boxing, MMA or Muay Thai) in Pencak Silsat in order to achieve peak performance, athletes are required to have high performance and the role of coaches must innovate in implementing effective training methods. Currently, Pencak Silat coaches must dare to innovate and try to combine training methods by involving the use of modern tools such as augmented reality.

Conceptually, augmented reality is interpreted as a technology that presents a training atmosphere with a combination of virtual objects and real world (Soltanabadi et al., 2023; Usra et al., 2024). In addition, training session with augmented reality presented something new, and different from traditional training, young athletes acquired and learned numerous skills from a 3-D avatar (Cossich et al., 2023). Involving augmented reality in long-term training programs must be provided to young combat sport athletes, considering the convenience to access anytime, anywhere (Franzò et al., 2023). On the other hand, Pérez-Muñoz et al. (2024) explained that augmented reality assisted a fun training experience, and increased motivation. In particular, augmented reality has been claimed to be used as training to improve several important aspects, such as psychology, health (Piqueras-Sola et al., 2024), and the performance of young athletes in competition (Sohail et al., 2022). In addition, Chang et al. (2019), explained that another benefit that can be provided by the continuous application of augmented reality technology was an increase in high motor skills. Although the benefits of augmented reality had been reported by previous studies (Calabuig-Moreno et al., 2020), unfortunately the benefits of augmented reality on exercise behavior, and technical performance among young athletes had not been investigated.

Exercise behavior is a theory that explains certain actions or behaviors in young athletes during training sessions to achieve goals in sports (Chen et al., 2022). Basically, exercise behavior must be fostered and improved

optimally, because this is closely related to the development of awareness of young athletes' behavior in carrying out exercise (Yan et al., 2024). In addition, the benefits of exercise behavior were confirmed by several previous studies, for example, regular exercise behavior had the potential to reduce the risk of chronic diseases, avoid obesity (Liu et al., 2024) to the risk of mental illness (Li et al., 2024; Harada, 2022). Young athletes are in puberty, which is a golden period to develop skills and good training habits, however, in this period, young athletes experience behavioral changes such as anxiety and high stress, which has an impact on low participation in training (Boonsem et al., 2021). Exercise behavior can be improved among young athletes by several factors, such as family, social, school, individual (Chen et al., 2022).

Technical performance is an absolute item or factor that must be the focus among young athletes (Usra et al., 2024). High technical performance is the main key for young athletes to show effective movements (e.g., punches, kicks) during competition (Brechney et al., 2022). In addition, many previous studies acknowledged that without high technical performance, young athletes will not develop their skills, and it is difficult to achieve success in combat sports. On the other hand, technical performance is an important factor similar with physical, psychological or tactical factors, thus technical performance among young athletes must be optimally improved (Folhes et al., 2023). Meanwhile, Zhang et al. (2022), explained that young athletes with high technical performance carry out attack and defense strategies effectively, which allows a great opportunity to achieve victory.

Previous studies had explored the application of augmented reality, but there was a marked gap in its application, mostly in the context of physical education (Chang et al., 2019; Liang et al., 2023; Moreno-Guerrero et al., 2020; Paramitha et al., 2024), and ignored the potential of augmented reality in the field of combat sports training, especially Pencak Silat. In addition, there was still limited research that thoroughly investigated the application of augmented reality during long-term Pencak Silat training to improve exercise behavior, and technical performance among young athletes. Thus, this study aims to analyze the impact of augmented reality during Pencak Silat training to improve training behavior, and technical performance among young athletes. Our hypothesis is young athletes in the augmented reality group during Pencak Silat training achieved higher results in exercise behavior, and technical performance variables compared to the control group.

Methods

Participants

Participants in this research are from young Pencak Silat athletes at Medan State University (Indonesia). The a priori sample size requirement was measured using G*Power (version 3.1.9.4; Franz Faul-University of Kiel, Germany). The F test with ANOVA repeated measures analysis (effect size f=0.30 [large], α err prob=0.05, power [1-β err prob]=0.80, number of groups=2, number of measurements=3). The calculation results showed that at least 20 young Pencak Silat athletes were needed to participate in this study. However, considering the dropout rate in training was 10%, it was planned to involve at least 60 young athletes.

Then, screening was carried out using inclusion criteria (Fig. 1), such as: (I) young male and female athletes, (II) not suffered severe injuries in the last 1 month, (III) did not have any history of chronic diseases (heart, asthma), (IV) did not have any visual and hearing impairment, (V) did not participate in national or international championship events, (VI) 100% attendance rate, and (VII) free from mental conditions that can affect the pre-, mid-, and posttest processes. Their biodata were collected, and stored by the research team. In the final screening, 10 young athletes were excluded because they failed to meet the rules stated in the inclusion criteria. Thus, this resulted in a final

study group of 50 young athletes, and they were randomly assigned (https://www.randomizer.org/) to enter the ART (n=25; male=15; female=10), and TT (n=25; male=15; female=10) (Table 1). The Human Research Ethics Committee of Medan State University, Indonesia (ethics approval code: 0601/UN33.6/LL/2024) was granted permission for the study. In addition, informed consent was obtained from the young athletes, and their parents. This study follows the ethical rules issued by the Declaration of Helsinki (2024).

Table 1. Participant characteristics data from both training groups

Characteristic	ART (n=25)	TT (n=25)
Age (years)	18.3±0.90	18.0±0.79
Height (cm)	163±1.98	164±2.36
Weight (kg)	59.2±2.13	60.3±2.10
BMI (kg/m2)	22.0±0.95	22.8±1.03
Pencak Silat training experience (years)	1.39±0.48	1.51±0.50
Augmented reality training experience (years)	1.25±0.44	1.32±0.47

ART=Augmented reality training, TT=Traditional training, *n*=Participants, BMI=Body mass index.

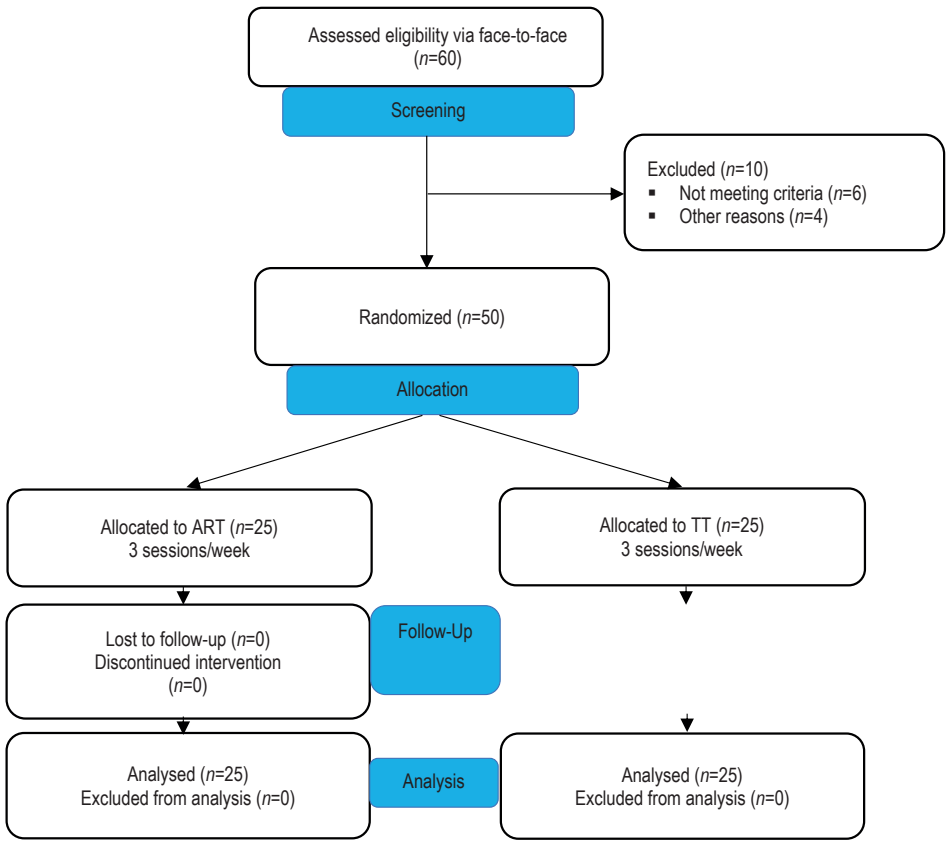


Figure 1. Diagram Flow of participants

Measure

Exercise Behavior. The test used to measure exercise behavior included three test questions, (i) exercise intensity, (ii) exercise time, and (iii) exercise frequency (Li et al., 2024). This test was answered on a Likert scale with 1–5 points according to its level. In this study, the scoring was modified, the score for each test (exercise intensity, exercise time, and exercise frequency) was used for statistical analysis, as a quantitative indicator towards the evaluation of young athletes' exercise behavior. If the group obtained higher score, then the amount of physical exercise behavior would be higher. In this study, the intra-class correlation coefficient (ICC) value of each question in physical exercise intensity, exercise time, and exercise frequency was tested (Table 3).

Technical Performance. In order to measure the level of technical performance ability of young athletes, an instrument adopted from previous studies was applied (Usra et al., 2024). This instrument has 2 types of tests, namely: (i) target punching test, the athlete stood upright facing a punching bag (Bran-JUOIFIP), after hearing the command "GO", the participants punch the target on the punching bag as quickly as possible for 1 minute, and (ii) target kick test, the athlete was required to kick towards the target on the punching bag for 1 minute (Kabadayı et al., 2022). Scoring was calculated by counting the number of punches and kicks that hit the target. If the number of punches and kicks that hit the target increased, the technical performance score would be higher. In this study, the ICC value has been tested and it is presented in Table 3.

Design and Procedures

A 9-week true experimental study with details of 3 sessions/week was adopted in this study. This study was conducted from November 2024 to January 2025 at the gymnasium of Medan State University. In the first week, all participants carried out a pre-test, namely filling out an exercise behavior questionnaire (physical exercise intensity, exercise time, exercise frequency), and a technical performance test (target punching test, target kick test) from 09:00 to 12:00 am. In the second week, participants were randomly assigned to enter the ART and TT groups, both groups carried out their respective programs until week 5. Then in week 6, all participants in ART and TT carried out a mid-test at 09:00 to 12:00 a.m. The ART and TT programs were continued in weeks 7 to 8. In week 9, all participants carried out a post-test at the same time as the previous test (Fig. 2). All activities from start to finish were closely monitored by the research team.

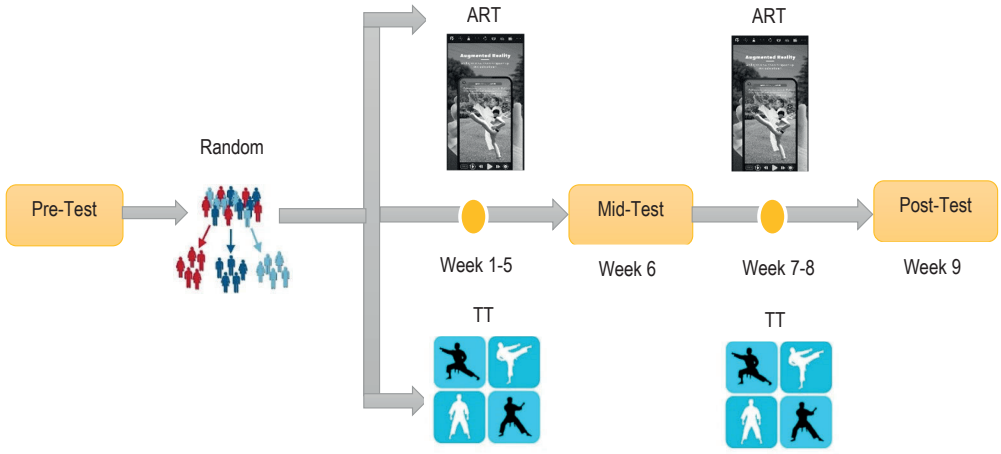


Figure 2. Experimental design

ART Program

The ART program was carried out 3 sessions per week, on Monday, Wednesday, and Friday during the Pencak Silat training schedule from 07:00 am to 08:00 am. The trainers assigned to the ART group have 10 years of training experience, and there are experts in the field of technology-based Pencak Silat. The participants carried out ART sessions for 60 minutes in one day. Daily activities in ART started with warm-up that focuses on the muscles throughout the body for 5 minutes. Continued with the main training, the augmented reality application was installed on an Android smartphone with the type Infinix Note 40 Pro Plus + 5G, and Samsung Galaxy A55 5G and distributed to the participants. In augmented reality, an avatar or animation demonstrated Pencak Silat movement skills, such as punches and kicks. Participants were instructed to analyze each Pencak Silat movement skill through the augmented reality technology application for 10 minutes. After that, participants conducted independent training for 40 minutes. If participants forgot the movements in Pencak Silat, they would allowed to observe them again in augmented reality. The activity ended with 5-minute cool-down (Table 2).

Table 2. 9-week ART program

Activities	Duration	Decription
Warm-up	5 min	The initial activity for participants was to stretch the muscles of the upper and lower body.
Main exercise	10 min	First, participants were instructed to analyze each punch and kick movement in an augmented reality tool.
	40 min	After observing an avatar in augmented reality demonstrating each movement, participants were instructed to practice independently, and if participants forgot the punch or kick movements, they could rewatch the augmented reality.
Cool-down	5 min	After the training activity was completed, all participants were instructed to perform a cool-down on the muscles throughout the body.

Control Group Program

The trainer in charge of the TT group had 12 years of training experience and was an expert in Pencak Silat. Participants in the control group were instructed to maintain their daily routine (TT) for 60 minutes. No special training or exercise program was given to this group. The TT group program was implemented according to the schedule applied to the ART group.

Statistical analysis

Descriptive statistics were presented in mean ± standard deviation. Shapiro-Wilk's ($p \geq 0.05$) was used to analyze the normality of the data and the reliability value of each variable was presented in ICC. We conducted the Delta percentage ($\Delta\%$) test in this study. In addition, Two-Way Repeated Measure (T-WRM) ANOVA, was used to test the effects of condition (ART vs. TT), time (pre- vs. mid- vs. post-test), and the interaction between condition (ART vs. TT) vs. time (pre- vs. mid- vs. post-test) on exercise behavior, and technical performance. The effect size for ANOVA was determined based on partial eta squared ($\eta p2$) as follows: $\eta p2<0.01$ (small effect), $0.01<\eta p2<0.06$ (medium), and $\eta p2>0.14$ (large effect) (Cohen, 2013). The Cohen's d was calculated for the pairwise differences: trivial (<0.20), small (0.2<0.50), moderate (0.5<0.80), and large (>0.80). Bonferroni post-hoc test was used for pairwise comparisons on EB and TP. The significance level of this study was set as 0.05. All data were analyzed using Jamovi v.2.3.28 (The Jamovi Project, Sydney, Australia).

Results

Table 3 shows that the ICC value is in the range of 0.88–0.95, which proves that the reliability value of each parameter (EB and TP) is in the high category. In addition, it can be observed that the data in this study distributes normally (Table 3). Meanwhile, for descriptive statistical values including mean, standard deviation, ICC to delta percentage ($\Delta\%$), we present them in Table 4.

Table 3. Reliability and normality of variable test

Parameters	ICC	ART			TT		
		SW-Pre	SW-Mid	SW-Post	SW-Pre	SW-Mid	SW-Post
Exercise Behavior							
Training intensity (score)	0.889	0.093	0.109	0.215	0.149	0.131	0.155
Practice time (score)	0.870	0.134	0.070	0.149	0.088	0.080	0.096
Exercise frequency (score)	0.924	0.231	0.189	0.166	0.133	0.178	0.146
Technical Performance							
Target punching test (score)	0.977	0.098	0.279	0.118	0.221	0.198	0.247
Target kick test (score)	0.940	0.065	0.060	0.135	0.077	0.071	0.088

ICC=Intra-class correlation coefficient; SW=Shapiro-Wilk's; ART=Augmented reality training; TT=Traditional training; EB=Exercise Behavior; TP=Technical Performance.

Table 4. Descriptive statistics

Parameters	Condition	Pretest Mean±SD; (95% CI)	Midtest Mean±SD; (95% CI)	Posttest Mean±SD; (95% CI)	%Δ
Exercise Behavior					
Exercise intensity (score)	ART (*n*=25)	1.80±0.57 (1.56 to 2.04)	2.80±0.57 (2.56 to 3.04)	4.60±0.50 (4.39 to 4.81)	59.92
	TT (*n*=25)	1.72 0.45 (1.53 to 1.91)	2.72±0.45 (2.53 to 2.91)	3.76±0.43 (3.58 to 3.94)	48.19
Exercise time (score)	ART (*n*=25)	1.64±0.49 (1.44 to 1.84)	2.80±0.50 (2.59 to 3.01)	4.52±0.51 (4.31 to 4.73)	66.08
	TT (*n*=25)	1.96±0.53 (1.74 to 2.18)	3.20±0.50 (2.99 to 3.41)	4.44±0.50 (4.23 to 4.65)	51.01
Exercise frequency (score)	ART (*n*=25)	1.72±0.54 (1.50 to 1.94)	3.48±0.58 (3.24 to 3.72)	4.80±0.40 (4.63 to 4.97)	70.13
	TT (*n*=25)	1.80±0.57 (1.56 to 2.04)	2.96±0.53 (2.74 to 3.18)	4.04±0.61 (3.79 to 4.29)	50.47
Technical Performance					
Target punching test (score)	ART (*n*=25)	11.3±1.72 (10.6 to 12.0)	16.0±1.73 (15.3 to 16.7)	19.3±1.82 (18.6 to 20.1)	31.11
	TT (*n*=25)	13.5±1.39 (12.9 to 14.1)	14.6±1.42 (14.0 to 15.1)	15.8±1.46 (15.2 to 16.4)	8.18
Target kick test (score)	ART (*n*=25)	10.2±1.54 (9.61 to 10.9)	16.4±1.58 (15.8 to 17.1)	19.3±1.88 (18.5 to 20.1)	39.23
	TT (*n*=25)	11.8±1.49 (11.2 to 12.5)	13.3±1.49 (12.7 to 13.9)	14.9±1.86 (14.1 to 15.6)	12.37

ART=Augmented reality training, TT=Traditional training, SD=Standard deviation, CI=Confidence interval, %Δ=Delta percentage, ES=Effect size.

The results of T-WRM ANOVA (Table 5) reveals that there are significant condition effects with ($F_{(1.48)}$=6.38; p=0.019; η$p2$=0.21), time ($F_{(1.48)}$=693.19; p<.001; η$p2$=0.96), and condition vs. time interaction ($F_{(1.48}$=23.80; p<.001; η$p2$=0.49) on the EB parameters in the exercise intensity indicator. At the same time, the effects of condition ($F_{(1.48)}$=5.89; p=0.023; η$p2$=0.19), time ($F_{(1.48)}$= 400.97; p<.001; η$p2$=0.94), condition vs. time interaction ($F_{(1.48)}$=4.57; p=0.015; η$p2$=00.16) on the training time indicator and training frequency on the effects of condition ($F_{(1.48)}$=9.39; p=0.005; η$p2$=0.28), time ($F_{(1.48)}$=446.11; p<.001; η$p2$=0.94), and condition vs. time ($F_{(1.48)}$=16.08; p<.001; η$p2$=0.40). Further results of T-WRM ANOVA show that there is a significant condition effect with ($F_{(1.48)}$=13.9; p=0.001; η$p2$=0.36), time ($F_{(1.48)}$=353.6; p<.001; η$p2$=0.93), and condition vs. time interaction ($F_{(1.48)}$=97.1; p<.001; η$p2$=0.80) on the TP parameters in the target punching test indicator. Meanwhile, the target kick test indicator shows a condition effect ($F_{(1.48)}$=25.4; p=0.001; η$p2$=0.51), time ($F_{(1.48)}$=394.3; p<.001; η$p2$=0.94), and the condition vs. time interaction ($F_{(1.48)}$=102.7; p<.001; η$p2$=0.81) (Table 5).

Post-hoc Bonferroni tests showed that the increase in EB scores from pre-, mid-, to posttest was higher in ART than in TT (Fig. 3). Furthermore, we also observed that the increase in TP scores from pre, mid-, to posttest was higher in ART than in TT (Fig. 4).

Table 5. Summary of T-WRM ANOVA Results

Parameters	F(1.48)	p	η_{p2}
EB			
Exercise intensity (score)			
Condition	6.38	0.019	0.21
Time	693.19	<.001	0.96
Condition vs. time interaction	23.80	<.001	0.49
Exercise time (score)			
Condition	5.89	0.023	0.19
Time	400.97	<.001	0.94
Condition vs. time interaction	4.57	0.015	0.16
Exercise frequency (score)			
Condition	9.39	0.005	0.28
Time	446.11	<.001	0.94
Condition vs. time interaction	16.08	<.001	0.40
TP			
Target punching test (score)			
Condition	13.9	0.001	0.36
Time	353.6	<.001	0.93
Condition vs. time interaction	97.1	<.001	0.80
Target kick test (score)			
Condition	25.4	<.001	0.51
Time	394.3	<.001	0.94
Condition vs. time interaction	102.7	<.001	0.81

EB=Exercise Behavior, TP=Technical Performance.

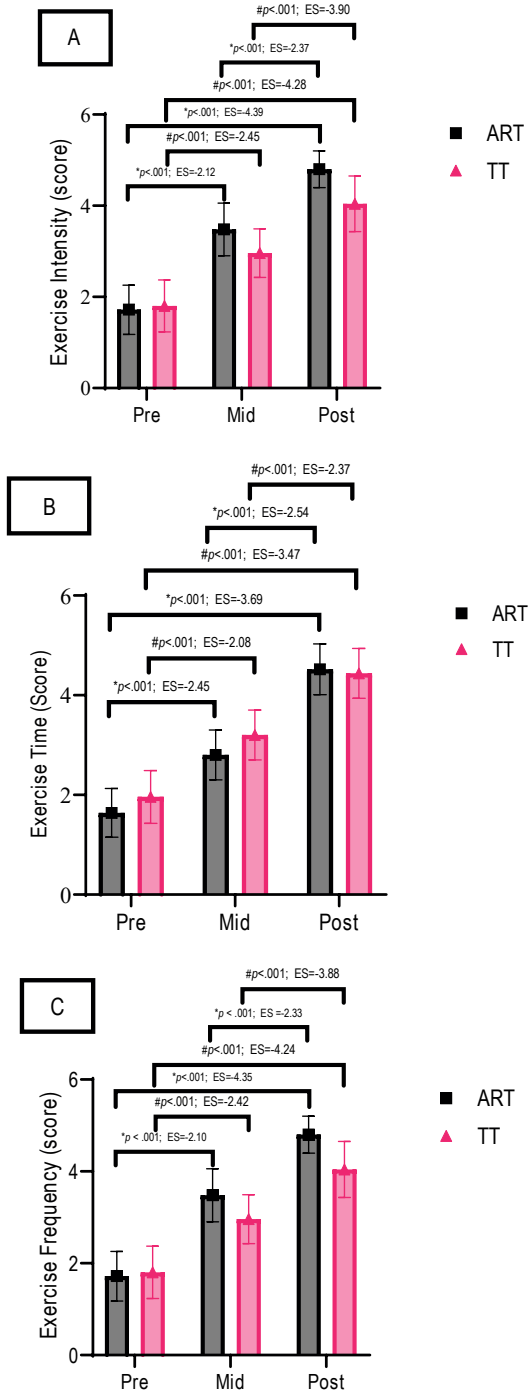


Figure 3. Changes in exercise behavior: (A) exercise intensity, (B) exercise time, and (C) exercise frequency. *Significant differences between pre-, mid-, and post-test in ART. #Significant differences between pre-, mid-, and post-test in TT.

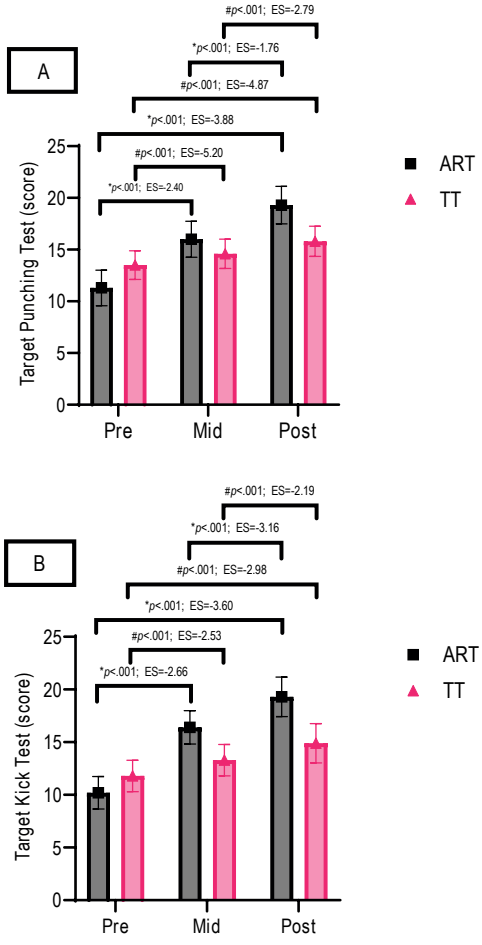


Figure 4. Changes in technical performance: (A) target punching test, and (B) target kick test. *Significant differences between pre-, mid-, and post-test in ART. #Significant differences between pre-, mid-, and post-test in TT.

Discussion

Our current research aims to investigate the effects of ART during Pencak Silat training on improving exercise behavior (training intensity, training time, training frequency), and technical performance (punching, kicking) among young athletes.

This study acknowledged two main findings. First, this study answered hypothesis, that ART has a higher positive effect than TT on improving exercise behavior related to indicators of exercise intensity, exercise time, and exercise frequency of young athletes. This is because the two training methods have different characteristics and training stages. For example, ART presented a 3-D avatar animation in a real environment (Loia & Orciuoli, 2019), so that young athletes can analyze in detail every movement demonstrated by the avatar (Cossich et al., 2023). Additionally, another advantage of the ART program is that young athletes can observe the virtual avatar anywhere

and anytime (i.e., during breaks or at home), in case they forget the movements (Bali & Fridhi, 2023), in this way it has the potential to improve the quality of exercise behavior (Salatino & Burin, 2024).

Technology such as augmented reality is currently a new innovation in combat sport training (Septri et al., 2023), especially Pencak Silat, and this can provide a meaningful movement experience for young athletes in conducting long training sessions effectively (Usra et al., 2024). A previous study reported that augmented reality presented during combat sport training sessions can trigger athletes to increase their interest in training (Zhang & He, 2022). Another report revealed that augmented reality technology was a significant major factor in increasing aspects of self-efficacy, academic performance (O'Connor & Mahony, 2023), repetitive behaviors, and executive function (Nekar et al., 2022). On the other hand, several researchers acknowledged that the presence of augmented reality created a realistic, interesting, and fun training environment (O'Connor & Mahony, 2023; Viscione & D'elia, 2019) and it was different to the routine training from coaches, and more traditional. We found an interesting fact that in the first week, athletes showed negative behavior (unenthusiastic) in carried out training activities through augmented reality, which cause the ART score results were smaller than TT in the pre-test stage (Fig. 3). However, in the second week there was a significant change in behavior, which shows the difference in scores in the pretest, midtest to posttest stages. Ng et al. (2019) supports the findings in this research, where the application of an augmented reality program causes significant changes in psychological behavior. According to Nekar et al. (2022), augmented reality was able to foster the intention and enthusiasm of young athletes to train hard. In line with Paramitha et al. (2024), the continuous use of augmented reality during training sessions was an effective way to increase the level of grit and learning satisfaction among young athletes.

Basically, sports behavior among young athletes can be influenced by several important factors such as the surrounding environment (Nekar et al., 2022), coach behavior (Choi et al., 2020), harmonious relationships between coaches, and young athletes (Zhang & Rhim, 2024) until the application of a training method. This finding is in line with Liang et al. (2023), who reported that the augmented reality training method group, and TT (control), both had positive effects on the development of young athletes, but the augmented reality training method group showed higher scores than TT in increasing motivation, and learning behavior in young athletes. These results proved that low exercise behavior in young athletes would be improved if the coach applied the right training method.

The second finding in this study proves that the ART group had a higher positive effect than TT on improving technical performance variables among young athletes. It was observed from the movement experience presented by each group, ART was able to create a fun, challenging training process, and provide guidance for young athletes to learn each movement (e.g., punching, kicking) in Pencak Silat. In addition, the ART program provided clear guidance about incorrect movements, and should not be done until the movement is correct. A previous study reported similar results, integrating augmented reality-based training for 11 weeks proved effective in improving technical performance among young karate and Pencak Silat athletes (Usra et al., 2024).

Basically, to learn punching and kicking movements in Pencak Silat, the application of sophisticated, modern technological tools such as augmented reality was needed, and it was a necessity in sports and physical education (Pérez-Muñoz et al., 2024), because augmented reality helped coaches to demonstrate punching and kicking movements correctly to young athletes. If young athletes were continuously and repeatedly given stimuli through augmented reality, the cognitive ability to record each movement would be better (Salatino & Burin, 2024), and the ability to mastering each movement would be faster (Nekar, Kang et al., 2022). In addition, we agreed with other studies that showed the integration of augmented reality technology during training sessions had a positive

impact on motoric aspects (Chang et al., 2019; Moreno-Guerrero et al., 2020). Likewise, the benefits of using augmented reality during teaching in physical education had been confirmed by several research groups, these benefits included improving physical performance and skills development (Chang et al., 2019; Liang et al., 2023). Some researchers reported an increase in motor skills (Pérez-Muñoz et al., 2024).

Strengths, Limitations, Future study prospects

The main strength of this research was creating an easy-to-use augmented reality training program that was specifically designed for young athletes in Pencak Silat. In addition, the 3D avatars presented in augmented reality technology were made as realistic as possible, so they were similar to real-world conditions, which allowed athletes to have no difficulty in learning movement tasks. However, we realized that there were several limitations in this research, for example: (i) the number of meetings was only 9 weeks, which could not fully cover long-term research on adaptation to technical performance training in Pencak Silat, (ii) participants only involved male gender, thus limiting generalization to a wider population such as women. In addition, (iii) the program designed in ART was specifically for young Pencak Silat athletes, and could not be applied to other combat sports. Therefore, several improvements in the future research are recommended. First, increasing the number of meetings, for example 14 weeks or more. Second, involving a more diverse number of participants by examining the gender between young male and female athletes, age. Third, involving young athletes from other types of combat sports (e.g., Karate, Taekwondo, Judo, Muay Thai, Capoeira, Wing Chun, and Boxing). Finally, creating a more diverse augmented reality training program that includes several other types of combat sports.

Conclusion

This study highlighted that the demonstration of ART and TT for nine weeks had significant effects towards the changes in exercise behavior, and technical performance. The ART group showed significantly higher than TT. Thus, the conclusion in our current study proves that the implementation of the ART program can improve exercise behavior (e.g., exercise intensity, exercise time, exercise frequency), and technical performance (e.g., punching, kicking) among young Pencak Silat athletes.

Practical applications

Promoting augmented reality innovation into combat sport training, specifically Pencak Silat, is a problem that must be overcome in the future. If the augmented reality tools have not been created and applied from now on, then the improvement of achievement among young athletes will be less than optimal. Contributions and implications for the practice of using the advantages of augmented reality can be an innovative and effective training in improving exercise behavior (e.g., training intensity, training time, training frequency), and technical performance (e.g., punching, kicking) among young Pencak Silat athletes. In fact, it is expected that the presence of this research can solve the shortcomings in integrating technology, especially augmented reality, in Pencak Silat training. In addition, in future practice, it is expected that young athletes and coaches can continuously use augmented reality technology to optimize the achievement of training goals.

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GENETIC DETERMINANTS OF NON-CONTACT MUSCLE INJURY: THE ROLE OF THE CREATINE KINASE, MUSCLE (CKM) RS8111989 POLYMORPHISM IN PHYSICALLY ACTIVE CAUCASIANS

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Abstract The creatine kinase, muscle (*CKM*) rs8111989 polymorphism has been repeatedly linked to athletic performance, yet its role in susceptibility to non-contact muscle injury remains unclear. This study examined the association between *CKM* rs8111989 and the risk of non-contact muscle injury in 269 physically active Caucasian adults. Participants were classified into a study group with a self-reported history of non-contact muscle injury (n=139) and an injury-free control group (n=130). Among injured participants, 25 reported one injury and 114 reported ≥2 injuries. Most participants were engaged in endurance-oriented disciplines, predominantly long-distance running. Genomic DNA was isolated from buccal swabs and genotyped using real-time polymerase chain reaction (real-time PCR). Logistic regression models (dominant, recessive, codominant, overdominant, log-additive) were applied to test associations between rs8111989 and injury status (any injury, one injury, multiple injuries), with age and body mass index (BMI) included as covariates. The rs8111989 alternative-allele frequency was 0.690 overall (controls 0.712; injury group 0.669; 1 injury 0.720; ≥2 injuries 0.658). No statistically significant associations were observed between rs8111989 genotypes and either the presence or number of non-contact muscle injuries after Bonferroni correction for multiple testing. These findings indicate that *CKM* rs8111989 is unlikely to exert a major independent effect on non-contact muscle injury risk in this cohort. Replication in larger, prospectively monitored, and sport-specific samples, ideally within polygenic frameworks, is warranted.

Key words: sports genetics, creatine kinase, muscle, rs8111989, non-contact muscle injury

Introduction

The pursuit of peak athletic performance is a complex interplay of training, environment, and, fundamentally, genetics (Mijaica et al., 2025). While rigorous physical activity is essential for achieving elite status, it also carries an inherent risk of musculoskeletal injury, which can significantly derail an athlete's career and overall well-being (Filbay et al., 2022). Understanding the underlying biological factors that predispose individuals to muscle damage is a critical area of sports medicine and genetics research (Leońska-Duniec, 2025).

Musculoskeletal injury risk is a multifactorial trait influenced by environmental and genetic factors. Previous studies have identified associations between injury susceptibility and genes involved in i) inflammation e.g. interleukin 6 (*IL6*), ii) structural organization of muscle fibers and the extracellular matrix e.g. alpha-actinin-3 (*ACTN3*) and collagen type V alpha 1 chain (*COL5A1*), iii) growth and repair pathways e.g. insulin-like growth factor 2 (*IGF2*), iv) membrane integrity, ion transport, and signaling pathways e.g. caspase 8 (*CASP8*), v) regulators of vascular function and perfusion e.g. angiotensin I-converting enzyme gene (*ACE*), and vi) metabolism and energy homeostasis e.g. adenosine monophosphate deaminase 1 (*AMPD1*) (Leońska-Duniec, 2025; Leońska-Duniec et al., 2025; Lim et al., 2021; Lulińska-Kuklik et al., 2019; Marques et al., 2024; Stastny et al., 2019). Among the numerous genetic markers investigated, the creatine kinase, muscle (*CKM*) gene, given its role in muscle energy metabolism and contraction, has emerged as a compelling candidate influencing both muscle performance and injury susceptibility in physically active populations (Chen et al., 2021; Echegaray & Rivera, 2001; Varillas-Delgado et al., 2023).

The CKM enzyme plays a pivotal role in cellular energy homeostasis, catalyzing the reversible transfer of a phosphate group from phosphocreatine to ADP, thereby rapidly regenerating ATP, particularly in tissues with high and fluctuating energy demands like skeletal muscle (Appel et al., 2021; Baumert et al., 2016). Variations in the *CKM* gene, such as the rs8111989 A/G single nucleotide polymorphism (SNP), are hypothesized to modulate the efficiency of this energy system, consequently affecting muscle function and resilience (Ginevičienė et al., 2021). Indeed, meta-analyses have established a significant association between this polymorphism and athletic phenotype, with the G allele and GG genotype being overrepresented in power athletes compared to the general population, suggesting a beneficial role in strength and power-related performance (Chen et al., 2021).

Despite the substantial progress in identifying genetic determinants of sports performance, the genetic basis of sports-related injuries remains comparatively underexplored. In contrast to anterior cruciate ligament (ACL) ruptures, which have been the focus of numerous epidemiological and mechanistic studies (Rahim et al., 2016), non-contact muscle injuries, such as strains and tears of the hamstrings, quadriceps, and calf muscles, are poorly characterized at the molecular level (Leońska-Duniec, 2025). Existing research has largely concentrated on extrinsic risk factors (e.g., training load, playing surface, or match congestion) and a limited set of intrinsic factors (e.g., age, previous injury), with relatively few studies addressing the contribution of genetic variation to muscle injury susceptibility (Green et al., 2020; Lim et al., 2021; Marques et al., 2024). Furthermore, most available genetic studies have been conducted in small, highly selective cohorts of elite athletes and frequently emphasize indirect markers of muscle damage (e.g., serum CK activity, delayed onset muscle soreness) rather than non-contact muscle injuries in broader physically active populations (Leońska-Duniec et al., 2025; Varillas-Delgado et al., 2023). This gap highlights the need for well-designed association studies that investigate specific polymorphisms, such as *CKM* rs8111989, in relation to objectively defined outcomes of muscle injury.

However, the relationship between the *CKM* rs8111989 variant and the occurrence of muscle injury is less clear and remains a subject of ongoing debate. Some research has suggested a potential link between this

polymorphism and muscle injury (Maestro et al., 2022; Varillas-Delgado, 2024; Varillas-Delgado et al., 2023). A recent study focusing on high-performance football players found that this polymorphism did not significantly affect the overall injury incidence during training or match exposure. This study, however, did report that players with the heterozygous GA genotype were more prone to experiencing severe injuries and muscle tears compared to homozygotes, suggesting that the polymorphism may influence the type or severity of injury rather than the overall frequency (Varillas-Delgado et al., 2023).

Therefore, the present study aimed to examine the association between the *CKM* rs8111989 A/G polymorphism and the risk of non-contact muscle injury in a cohort of 269 physically active Caucasian individuals. We hypothesize that a specific allele or genotype of this polymorphism will be significantly associated with an altered risk of this kind of sport-related injury.

Materials and Methods

Participants

The Bioethics Committee at the District Medical Chamber in Gdansk (No. KB-8/22) approved the study. The investigation protocols were conducted ethically according to the World Medical Association Declaration of Helsinki and to the Strengthening the Reporting of Genetic Association studies statement (STREGA). Initially, 812 individuals were assessed for eligibility. Participants were excluded if they were underage, failed to submit complete documentation, did not provide consent for genetic testing, reported contact-related injuries, or did not meet the physical activity criteria. Ultimately, a total of 269 unrelated Caucasian individuals were recruited between 2014 and 2020; their characteristics are summarized in Table 1.

The selection of participants for the study and control groups was based on the International Physical Activity Questionnaire (IPAQ), which was used to verify the level and type of habitual physical activity. Most participants were engaged in endurance disciplines, predominantly long-distance running. In addition, a structured survey was administered to collect information on previous injuries, the circumstances in which they occurred, and general health status. All participants were Polish Caucasians, which minimized the risk of ethnicity-related bias and potential problems of population stratification.

The study group comprised 139 physically active individuals with a self-reported history of non-contact muscle injury. The most frequently affected regions were the thigh (61.9%), foot (37.3%), calf (25.2%), upper limb girdle (19.0%), and hip (6.3%). Moreover, 28% of the study group reported additional injuries, such as fractures, dislocations, and sprains. The control group consisted of 130 healthy, unrelated individuals with no reported history of this kind of muscle injury.

Body mass and body composition parameters were assessed using bioelectrical impedance analysis with an electronic scale (Tanita MC-780 P MA, Arlington Heights, Illinois, United States).

Table 1. General characteristics of the studied individuals

Group	Number of participants	Number of men	Number of women	Mean age	Mean height (cm)	Mean body mass (kg)	BMI
Main Groups							
Control	130	0	130	21,3	168	60.9	21,7
Individuals with previous muscle injuries	139	113	26	36	175,7	74,1	23,8
Subdivision by Number of Previous Injuries							
One previous injury	25	18	7	35,7	173,6	71,6	23,6
Two or more previous injuries	114	95	19	36,0	176,1	74,6	23,9

* A single participant may be classified into more than one group in the case of multiple injuries; values are presented to three significant figures. BMI – Body Mass Index

Genetic Analyses

DNA was isolated from buccal swabs (Copan FLOQSwabs, Interpath, Murrieta, Australia) collected from each participant, using the High Pure PCR Template Preparation Kit (Roche, Basel, Switzerland) in accordance with the manufacturer's protocol. Genotyping of the *CKM* rs8111989 polymorphism was carried out in duplicate using a TaqMan® Pre-Designed SNP Genotyping Assay (ID: C___3145002_10; Applied Biosystems, Waltham, MA, USA) on a C1000 Touch Thermal Cycler (Bio-Rad, Hercules, CA, USA). Each PCR reaction mixture contained 2.5 µL TaqPath™ ProAmp™ Master Mix (Applied Biosystems), 0.25 µL 10× assay mix, 1.0 µL distilled water, and 1.25 µL genomic DNA, in a final volume of 5 µL. The thermal cycling protocol consisted of a pre-read at 60°C for 30 s, followed by an initial denaturation at 95°C for 5 min, and 40 cycles of 95°C for 5 s and 60°C for 30 s (combined annealing and extension), with a final post-read at 60°C for 30 s. Fluorescence signals were recorded and allelic discrimination was performed using CFX Maestro 4.0 software (Bio-Rad).

Statistical Analysis

The association between the rs8111989 polymorphism in the *CKM* gene and muscle injury occurrence, as well as the analysis of variant frequencies and compliance with Hardy-Weinberg Equilibrium (HWE), was performed using STATISTICA v.13.1 (TIBCO Software Inc., http://statistica.io, accessed on 14.11.2025). Information regarding the characteristics of the studied polymorphism was obtained from the gnomAD database (https://www.nature.com/articles/s41586-020-2308-7, accessed on 14.11.2025).

Before conducting the association analysis, the control group was compared with the study group in terms of additional factors that could influence interactions with genetic variants. For this purpose, the following tests were applied Student's t-test for numerical variables (age, body mass, body height, BMI) and Chi-square test for the categorical variable (sex). Covariates were included in the main association models if their values differed significantly between the control and study groups (nominal p-value <0.05). Body mass index (BMI) was selected as a covariate to avoid excessive correction, since it already accounts for body height and mass.

For each analysis performed, both the nominal p-value and the value adjusted for multiple comparisons using the Bonferroni correction were reported.

Results

The study analyzed the rs8111989 polymorphic site in the *CKM* gene among 269 individuals, including the study group (n=139) and the control group (n=130).

Characteristics of the Groups and Studied Polymorphisms

The characteristics of the control and study groups are presented in Table 1. A preliminary analysis was also performed to compare the control group with the study group in terms of additional factors (covariates). Numerical factors were compared using Student's t-test and categorical variables using the Chi-square test (Table 2). It was shown that all numerical variables (age, height, body mass, BMI) and the categorical variable (sex) differ significantly between the groups.

Table 2. Results of statistical tests comparing the control and study groups in terms of additional factors

Factor	Test	p-value	t/Chi-square Statistic	95% Confidence Interval
Age	Student's t-test	<0,001	19,10	13,14 – 16,14
Height	Student's t-test	<0,001	9,59	6,48 – 9,81
Body Mass	Student's t-test	<0,001	10,61	10,68 – 15,52
BMI	Student's t-test	<0,001	6,78	1,51 – 2,74
Sex	Chi-square	<0,001	179,82	–

* Comparisons yielding nominal p-values <0.05 are shown; odds ratios with 95% confidence intervals (CI) were estimated using generalized linear models.

The study analyzed the polymorphism rs8111989 located in the *CKM* gene, which general characteristics are presented in Table 3.

Table 3. Characteristics of the studied polymorphism

rsID	gnomAD ID	Chromosome	Reference Allele	Alternative Allele	Gene (Location within Gene)	CADD (Variant Deleteriousness)
rs8111989	19-45895457-G-A	19	G*	A*	*CKM*	0,073

* The table presents alleles according to the reference genome and dbSNP, while in the study, alleles of the opposite orientation (C/T) were genotyped. These designations (C/T) are used in subsequent parts of this report.

The frequency of the studied polymorphism for the alternative allele, along with a comparison to population database values (GnomAD), is presented in Table 4.

Table 4. Frequency of the studied polymorphism for the alternative allele

rsID	GnomAD european (non-Finnish)	Entire Study	Control Group	Study Group	1 Previous Injury	2 or more previous Injuries
rs8111989	0,105	0,690	0,712	0,669	0,720	0,658

Analysis of deviations from HWE

A HWE test was performed, and the results in the form of p-values are presented in Table 5. The test revealed a significant deviation in the entire sample (p=0.049), in the study group (p=0.017), and in the subgroup of participants with multiple injuries (p=0.026). The control group (p=0.727) and the subgroup with one injury (p=0.341) remain in agreement with HWE.

For all individuals included in the study, charts (Figure 1) were also prepared showing the frequency of homozygotes and heterozygotes for the analyzed polymorphism.

Table 5. P-values of tests checking deviations from HWE for each subgroup

rsID	Entire study	Control group	Study group	One previous injury	Two or more previous injuries
rs8111989	0,049	0,727	0,017	0,341	0,026

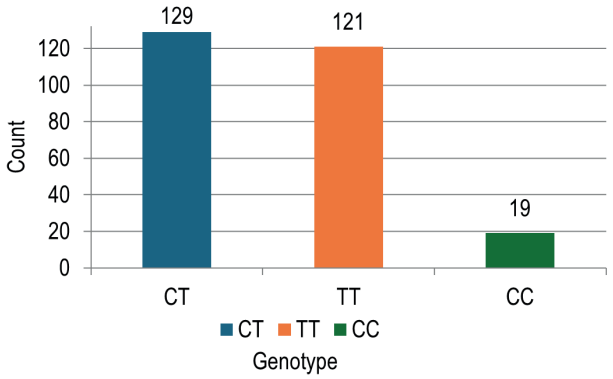


Figure 1. Distribution of homozygotes and heterozygotes for the rs8111989 polymorphism

Association analysis of polymorphism rs8111989 with covariates

For the studied polymorphism, it was examined whether there is a statistically significant association with any of the covariates: age, height, body mass, and BMI. The analysis was conducted using several models: dominant, recessive, codominant, overdominant, and log-additive.

None of the results reached the threshold of statistical significance in the association tests for the rs8111989 polymorphism with covariates (age, height, body mass, BMI) in the study group. The results of the analysis are presented in Table 6.

Table 6. Results of association analysis between additional factors (covariates) and studied variants

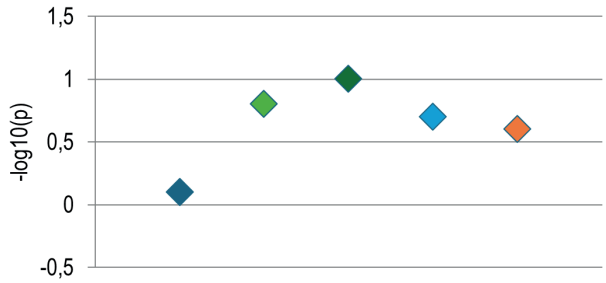
Covariate	Model	p	Adjusted p	Genotype	Mean Difference	95% CI Lower	95% CI Upper
Age	dominant	0,914	1	CT/TT vs CC	-0,38	-7,09	6,34
	recessive	0,949	1	TT vs CT/CC	0,10	-2,85	3,04
	codominant	0,988	1	-	-	-	-
	overdominant	0,902	1	CT vs CC/TT	-0,19	-3,13	2,76
	log-additive	0,927	1	-	-	-	-
Height	dominant	0,136	1	CT/TT vs CC	-2,71	-6,04	0,61
	recessive	0,743	1	TT vs CT/CC	0,44	-2,19	3,07
	codominant	0,523	1	-	-	-	-
	overdominant	0,414	1	CT vs CC/TT	-1,09	-3,68	1,51
	log-additive	0,775	1	-	-	-	-

Covariate	Model	p	Adjusted p	Genotype	Mean Difference	95% CI Lower	95% CI Upper
Body Mass	dominant	0,487	1	CT/TT vs CC	-2,50	-9,29	4,29
	recessive	0,586	1	TT vs CT/CC	1,18	-3,05	5,41
	codominant	0,661	1	-	-	-	-
	overdominant	0,405	1	CT vs CC/TT	-1,75	-5,85	2,35
	log-additive	0,605	1	-	-	-	-
BMI	dominant	0,818	1	CT/TT vs CC	1,59	-11,93	15,12
	recessive	0,467	1	TT vs CT/CC	0,91	-4,12	5,94
	codominant	0,614	1	-	-	-	-
	overdominant	0,407	1	CT vs CC/TT	0,72	-3,45	4,89
	log-additive	0,715	1	-	-	-	-

* Comparisons yielding nominal p-values <0.05 are shown; odds ratios with 95% confidence intervals (CI) were estimated using generalized linear models.

Association analysis of selected variants with muscle injuries

In the association analysis, several models were examined: dominant, recessive, codominant, overdominant, and log-additive. Figure 2 presents p-values (expressed as negative base-10 logarithms) for all models for the main comparison between the group of individuals with previous injuries and the control group. Associations were analyzed using generalized linear models, incorporating age and BMI as covariates. Results of the analysis are presented in Table 7.



The dots on the chart represent the negative base-10 logarithm of the p-values for the association of polymorphism rs8111989 and each model.

Figure 2. Summary chart of the results showing the association of the polymorphism with the occurrence of injuries.

Table 7. Results of associations between the studied variant and muscle injuries

SNP	Comparison	Model	p	Adjusted p	OR	CI Lower	CI Upper
		Dominant	0,8059	1,0000	1,13	0.42	3,08
		Recessive	0,1035	0,5175	0,65	0.38	1,09
	Study vs Control	Codominant	0,2254	1,0000	0,77	0.50	1,18
		Overdominant	0,0814	0,4070	1,59	0,94	2,68
		Log-additive	0,3463	1,0000	0,66	0,28	1,57
		Dominant	0,7099	1,0000	1,50	0,18	12,68
		Recessive	0,8933	1,0000	0,94	0,38	2,32
rs8111989	One injury vs Control	Codominant	0,9694	1,0000	1,01	0,48	2,14
		Overdominant	0,7517	1,0000	1,16	0,47	2,86
		Log-additive	0,9040	1,0000	1,10	0,23	5,22
		Dominant	0,8694	1,0000	1,09	0,39	3,09
		Recessive	0,0492	0,2462	0,57	0,32	0,99
	Multiple injuries vs Control	Codominant	0,1307	0,6536	0,71	0,45	1,11
		Overdominant	0,0417	0,2087	1,78	1,02	3,10
		Log-additive	0,2284	1,0000	0,57	0,23	1,42

* Comparisons yielding nominal p-values <0.05 are shown; odds ratios with 95% confidence intervals (CI) were estimated using generalized linear models.

No significant associations were found between the rs8111989 polymorphism and the risk of muscle injury after applying Bonferroni correction for multiple comparisons. Statistical significance was not observed in any of the analyzed genetic models (dominant, recessive, codominant, overdominant, log-additive) or comparisons (study vs control, 1 injury vs control, multiple injuries vs control).

Discussion

The present study investigated whether the *CKM* rs8111989 polymorphism is associated with the risk of non-contact muscle injury in a cohort of 269 physically active Caucasian adults. Contrary to our initial hypothesis, we did not observe any robust association between rs8111989 and the presence or number of non-contact muscle injuries, regardless of the genetic model applied or the comparison performed (study vs. control, one injury vs. control, multiple injuries vs. control). No statistically significant associations were found in any of the models tested, suggesting that this variant does not have a major independent effect on non-contact muscle injury risk in our cohort. However, these findings should be interpreted with caution and warrant replication in larger samples and in other athletic and physically active populations, ideally with prospective designs and more detailed phenotyping of muscle injuries. Given that injury susceptibility is shaped by multiple biological pathways, including inflammatory processes, muscle and connective tissue integrity, growth and repair, membrane integrity and signaling, vascular function, as well as energy metabolism, *CKM* variation may contribute in combination with other genetic and environmental factors rather than acting as an independent predictor (Leońska-Duniec, 2025). In addition, genetic variation may influence individual trainability, including the possibility of attenuated or adverse adaptations to specific movement patterns or training modalities, as suggested by previous systematic reviews (Petr et al., 2018).

These results are broadly consistent with recent work by Varillas-Delgado and coworkers (2023), who examined the rs8111989 polymorphism in 109 high-performance male football players. In that prospective cohort, *CKM* genotype did not influence overall injury incidence during training or match exposure. However, players with the AG genotype showed a higher frequency of severe injuries and muscle tears than GG or AA homozygotes, hinting at a possible role of rs8111989 in injury severity rather than incidence (Varillas-Delgado et al. 2023). Maestro and colleagues (2022) similarly reported that the AG genotype was more frequent in professional soccer players with musculoskeletal injuries, and particularly in those with severe injuries, compared with non-injured counterparts (Maestro et al., 2022). Our data, obtained in a broader physically active population rather than an elite football cohort, do not replicate a clear heterozygote "risk" pattern, and after correction for multiple comparisons, none of the observed effects reached statistical significance. Taken together, these findings suggest that if rs8111989 does influence muscle injury risk, the effect is modest and may be context-dependent (e.g., specific sport, load profile, or severity definition).

In contrast to the equivocal injury data, the relationship between *CKM* rs8111989 and exercise performance phenotypes is better documented (Ginevičienė et al., 2021; Fedotovskaya et al., 2013). The variant is located in the 3' untranslated region (3' UTR) of the *CKM* gene, a region known to modulate mRNA stability and translational efficiency (Mayr, 2019). Several studies and meta-analyses have shown that the G allele and GG genotype are overrepresented in power or mixed power–endurance athletes, while the A allele is more common among endurance athletes and is associated with more favorable VO□max responses to aerobic training (Chen et al., 2021; Ginevičienė et al., 2021). These data support the notion that rs8111989 contributes to interindividual differences in muscle performance and energy metabolism, even if the underlying molecular mechanisms remain incompletely understood.

From a biological standpoint, it is plausible that a variant affecting *CKM* expression or activity could modulate susceptibility to muscle damage. This gene encodes the muscle-specific isoform, which is densely localized at the M-line of sarcomeres and in proximity to the sarcoplasmic reticulum and mitochondria. This positioning allows CKM to serve as a central hub in the phosphocreatine (PCr) shuttle, rapidly regenerating ATP from ADP using PCr during high-intensity contractions. Efficient CKM activity helps buffer local ATP levels, stabilize ion gradients, and limit the accumulation of ADP, inorganic phosphate, and H□, all of which may contribute to fatigue and structural stress on the muscle fiber (Baker et al., 1994; Guimarães-Ferreira, 2014; Wallimann et al., 1992; Wallimann et al., 2011). In animal models, reductions in CKM activity are associated with impaired force production during high-intensity work and a shift toward more oxidative metabolism, whereas higher CKM activity seems advantageous for short, explosive efforts (Janssen et al., 2003; Steeghs et al., 1997).

The rs8111989 polymorphism, despite being non-coding, is thought to influence *CKM* expression and/or enzyme activity. Some studies suggest that the G variant is associated with lower CKM activity and a more "endurance-like" metabolic profile in skeletal muscle, potentially predisposing carriers to energy depletion and metabolic stress during intense or prolonged exercise (Maestro et al., 2022; Fedotovskaya et al., 2013; Zhou et al., 2006). Others have found that AA homozygotes are overrepresented among individuals with very high post-exercise serum CK responses (high "CK responders") after standardized muscle-damaging protocols, whereas GG homozygotes have been linked to a higher risk of exertional rhabdomyolysis in certain cohorts (Batavani et al., 2017). These apparently contradictory findings highlight that the relationship between rs8111989, CKM activity, and muscle damage is complex and likely modulated by additional genetic and environmental factors.

Conceptually, at least two non-mutually exclusive pathways could link *CKM* variation with non-contact muscle injury. First, intrinsic tissue vulnerability: altered CKM expression may impair ATP buffering during rapid or repetitive contractions, leading to local energy crisis, impaired Ca^{2+} handling, and increased susceptibility of the sarcolemma and cytoskeleton to microtears and Z-line streaming. Recurrent microdamage, if not fully repaired, could accumulate into clinically relevant strains or tears (Proske & Morgan, 2001). Second, exposure-driven risk: genotypes that favor power and sprint performance (e.g., those associated with higher force or rate of force development) may enable athletes to train and compete at higher intensities, thereby increasing mechanical load on muscle-tendon units independently of any intrinsic fragility. In such a scenario, *CKM* variants would influence injury risk indirectly through their impact on performance capacity and behavioral exposure rather than directly via tissue robustness (Leońska-Duniec, 2025; Mijaica et al., 2025).

Our findings do not provide strong support for either mechanism acting in isolation in a general physically active population. The lack of a clear association between rs8111989 and injury status, even in models adjusted for age and BMI, suggests that any effect of this polymorphism on non-contact muscle injury risk is small relative to more proximal determinants such as training load, previous injury, strength imbalance, flexibility, and neuromuscular control (Massidda et al., 2024; Varillas-Delgado, 2024). It is also notable that studies in elite footballers have reported genotype associations primarily with injury severity or etiology (e.g., muscle tear vs. other injuries), rather than with overall incidence, whereas our study classified participants based on the presence and number of self-reported non-contact muscle injuries without detailed grading of severity (Maestro et al., 2022; Varillas-Delgado et al., 2023). This phenotypic difference may partly explain the absence of concordant signals.

Recent research has shifted from single-variant analyses toward polygenic approaches, recognizing that musculoskeletal injury risk is likely influenced by the combined effect of multiple SNPs of small effect (Leońska-Duniec, 2025). Maestro et al. (2022) and Massidda et al. (2024) showed that total genotype scores integrating several "injury-related" polymorphisms, including *ACTN3*, collagen type I alpha 1 chain (*COL1A1*), *COL5A1*, *AMPD1*, and *CKM*, better discriminated between injured and non-injured players than any single variant alone (Maestro et al., 2022; Massidda et al., 2024). In this context, *CKM* rs8111989 may act as one modest contributor within a broader polygenic architecture of muscle injury susceptibility, with its effect size too small to detect reliably in a cohort of our size when considered in isolation.

Several methodological aspects of our study warrant consideration. First, the sample size (n=269) provides reasonable power to detect moderate effects but remains underpowered for small odds ratios (e.g., OR<1.4), especially after correction for multiple testing and stratification by number of injuries. Second, injury history was self-reported and retrospective, which introduces the risk of recall bias and misclassification, particularly for less severe injuries. However, the questionnaire specifically targeted non-contact muscle injuries, which individuals generally recall better than minor contusions or transient soreness. Nevertheless, we could not verify the reported injuries against medical records or imaging, and the retrospective design limited the standardization of injury diagnosis and severity grading. Consequently, some degree of misclassification (e.g., injury type, timing, or recurrence) cannot be ruled out. In addition, the study and control groups differed in key characteristics (notably sex and age distribution), and although age and BMI were included as covariates, residual confounding cannot be fully excluded. Third, the cohort included participants from various endurance-dominant disciplines, with relatively few athletes from pure power sports; if rs8111989 interacts with specific mechanical or metabolic demands (e.g., sprinting and repeated accelerations typical of football), its effect might be diluted in a more heterogeneous physically active sample. Fourth,

we observed deviations from HWE for rs8111989 in the overall sample and in the injury subgroups, while the control group remained in equilibrium. Genotyping was performed in duplicate using a validated TaqMan assay, which reduces the likelihood of systematic genotyping error, but selection bias and chance related to modest subgroup sizes cannot be excluded. Finally, we focused on a single *CKM* polymorphism. Given the regulatory complexity of this gene locus and its integration into broader metabolic networks, future work should examine additional *CKM* variants and their interactions with other genes involved in excitation–contraction coupling, extracellular matrix organization, and inflammation.

Despite these limitations, the study has several strengths. We specifically targeted non-contact muscle injuries, a clinically relevant but comparatively under-investigated phenotype in genetic research, and included a physically active, but not exclusively elite, cohort, which increases the generalizability of the findings beyond professional athletes. The use of standardized genotyping methods and consideration of key covariates (age, BMI, sex) in the association models also strengthens the internal validity of the results.

In summary, our data do not support a major role of the *CKM* rs8111989 polymorphism as an isolated determinant of non-contact muscle injury risk in physically active Caucasians. These findings align with previous reports showing no effect of rs8111989 on overall injury incidence in football players, while still being compatible with a small, context-dependent contribution to injury severity or etiology (Maestro et al., 2022; Varillas-Delgado et al., 2023). Future studies should prioritize larger, prospectively monitored cohorts, more granular injury phenotyping, and polygenic approaches that integrate *CKM* variants into broader genetic profiles. Such work will be essential to clarify whether *CKM* genotyping can meaningfully contribute to individualized injury risk stratification or whether its primary relevance remains confined to modulation of exercise performance rather than injury susceptibility.

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THE IMPACT OF A SHORT-TERM PERCEPTUAL TRAINING PROGRAM ON PERFORMANCE KINEMATICS AND DYNAMIC THREE-POINT SHOOTING ACCURACY IN BASKETBALL PLAYERS

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Abstract Purpose: This study investigated the impact of a short-term perceptual training program using the Dynavision-D2 device on dynamic three-point shooting accuracy and performance kinematics in semi-professional basketball players. Methods: Fifteen Semi-professional Basketball Players completed a three-week training program (three 30-minute sessions per week) alongside their regular practice. Pre- and post-training assessments measured shooting accuracy using the "90s dynamic three-point shooting" test and analyzed kinematic variables (e.g., wrist extension and ball release angles) using Dartfish software. Results: Results revealed a significant improvement in the three-point shooting accuracy ($p<.001$, Cohen's $d=1.70$), with post-training accuracy increasing from 15.7% to 18.2%. Regression analysis indicated significant differences in kinematic variables: Wrist Extension Angle: $p=0.004$, $R^2=0.388$, and Ball Release Angle: $p=0.05$, $R^2=0.161$. However, no statistically significant effects were observed for knee flexion ($p=0.710$), hip flexion ($p=0.418$), shoulder flexion ($p=0.629$), elbow flexion ($p=0.294$), and wrist flexion ($p=0.399$). Conclusion: The Short-Term Dynavision-D2 Training Program significantly improved three-point shooting accuracy and key kinematic variables in basketball players. The findings support the integration of cognitive-motor training into sports routines, highlighting its potential to enhance athletic performance.

Key words: cognitive training, motor skills, athletic performance, visual perception, neuromuscular coordination, movement analysis

Introduction

Optimal athletic performance is contingent upon the seamless integration of perceptual, cognitive, and motor skills, often triggered by rapidly changing visual cues during gameplay. According to Mann et al. (2007), perceptual-cognitive skills involve identifying and processing cues to make quick, informed decisions under pressure. Clutch performance- ability to maintain accuracy under pressure is a distinguishing trait of skilled players (Klostermann

et al., 2020). Effective team decision-making, grounded in coordination and communication, also contributes to scoring by enabling players to anticipate actions and respond accordingly (Moeinirad et al., 2022; Sirnik et al., 2022; Huang & Liu, 2022). The integration of perception and motor action, especially maintaining visual focus on the basket, supports precise execution in dynamic environments (Klostermann et al., 2020). For example, the visual skill "quiet eye," characterized by a final fixation on the target within a 3° visual angle for at least 100 milliseconds, has been shown to enhance shooting accuracy significantly (Vickers, 2007; Basevitch et al., 2020; Zhao & Zhao, 2023).

Previous literature lays emphasis on visual–perceptual abilities as equally important as biomechanical skills in dynamic sport environments. Basketball is a sport that demands rapid decision-making and strategic coordination game and, shooting stands out as one of the most complex and vital skill (Zhao & Zhao, 2023); As players must execute accurate shots in a forceful and often unpredictable environment, with the three-point shot being a common and strategic scoring method, typically performed after coordinated team efforts (Jin & Fan, 2023). Also, biomechanical research has linked several physical and technical factors, such as release angle, velocity, height, player fatigue, and positioning, to shooting performance (Sirnik et al.,2022); However, these do not fully account for shooting success, requiring the coordination with visual and perceptual skills for the shooting accuracy in basketball. Recent studies address the crucial role of visual skills in enhancing shooting accuracy, underlining their importance in interpreting visual cues and adjusting motor responses accordingly (Moeinirad et al., 2022; Sirnik et al., 2022; Huang & Liu, 2022). Moreover, encompassing various components that support decision-making and execution, dynamic visual acuity enables players to maintain clear vision while in motion, allowing for precise motor responses. In addition, visual search behaviors and processing speed are equally essential, as players must rapidly interpret game cues—such as the positions and movements of teammates and opponents—to make timely decisions (Jin & Fan, 2023). Basevitch et al. (2020) have also confirmed that gaze behavior during shooting is particularly influential; focusing on a specific target improves scoring precision (Basevitch et al., 2020).

Coaches and researchers have integrated sports vision training programs, which have been shown to enhance athletes' performance by improving eye–brain coordination, perception, and visual processing. In recent decades, advancements in vision training have introduced perceptual learning-based programs that target sport-specific visual skills, grounded in the understanding of the visual system's structure and function (Appelbaum & Erickson, 2018; Sirnik et al., 2022). One widely used tool in this field is the Dynavision D2, which has been validated as an effective device for training and assessing reaction time, visual awareness, and hand-eye coordination (Ong, 2020; Vater & Strasburger, 2021; Wells et al., 2014). Research by Vickers et al. (2019) reported that basketball players who maintained visual fixation on the ball during shooting despite defensive pressure achieved greater three-point shooting accuracy. Similarly, Mangine et al. (2014) found that visual tracking speed measured by the Dynavision D2 positively correlated with key performance metrics in professional players: steals ($r=0.77$, $p=.003$), assists ($r=0.78$, $p=.003$), and assist-to-turnover ratio ($r=0.78$, $p=.003$). However, general reaction time did not show a significant correlation with performance, suggesting visual tracking is a more critical factor.

Most previous research studies have tested the effect of sports vision training on shooting accuracy in sedentary shooting environments and its correlation with overall player performance. The current study aimed to address this gap by examining the effects of an early-season sports vision training program on college basketball players, focusing on its impact on dynamic three-point shooting accuracy and performance kinematics. Specifically, the study investigated whether a short-term perceptual training program using the Dynavision D2 would improve

dynamic three-point shooting accuracy and associated kinematic variables. It was hypothesized that the short-term training program would significantly enhance players' dynamic shooting accuracy.

Methods

Participants

Fifteen semi-professional basketball players from two local clubs were purposively selected for this study, based on coaches' recommendations. All participants were university students competing in regional championships. Ethical approval was granted by Yarmouk University's Institutional Review Board (IRB/2023/311), and the study complied with the Declaration of Helsinki (World Medical Association, 2013), ensuring participants' rights, dignity, and well-being. Informed consent was obtained, with participants assured of confidentiality and the right to withdraw at any time. The study procedures were clearly explained, and all questions were addressed. Inclusion criteria required participants to be healthy, injury-free for at least six months, and without vision problems. Exclusion criteria included wearing glasses or lenses, having vision impairments, or experiencing sickness that could affect balance or visual focus. Additionally, participants were instructed to abstain from caffeine for at least five hours before testing, and this was confirmed verbally prior to the test sessions.

Experimental Design

Participants took part in three weeks (3 sessions (30 minutes each)/week). Dynavision-D2 suggested a training program alongside their regular team practice schedule but on different weekdays. The Dynavision-D2 suggested intervention was conducted using Dynavision™ D2 Visuomotor Assessment Device (D2; Dynavision International LLC, West Chester, OH). The Dynavision-D2 training program was developed using pre-programmed training and assessment of the Dynavision-D2 software and specific tests that included the T-scope, reaction time, Endurance, Proactive mode A, and the Reactive mode B, with a total training time of 30 minutes for each session. The proposed training program was built through researchers' expertise recommendations and revision of previous literature and the basketball coach as presented in Table 1.

Table 1. Description of Dynavision-D2's Suggested Training Program Used

Task #	Training Model (Task)	Training Duration (Minutes/Session)
1	T-scope - L hand	3
2	T-scope - R hand	3
3	Reaction @ 30% green	2
4	Reaction: Training Upper	2
5	Reaction time	1
6	Endurance	5
7	Proactive mode A	2
8	Reactive mode B	2
Total training time for each session	20 minutes	+ 2 minutes warm-up + 1-minute break between tasks

Procedures

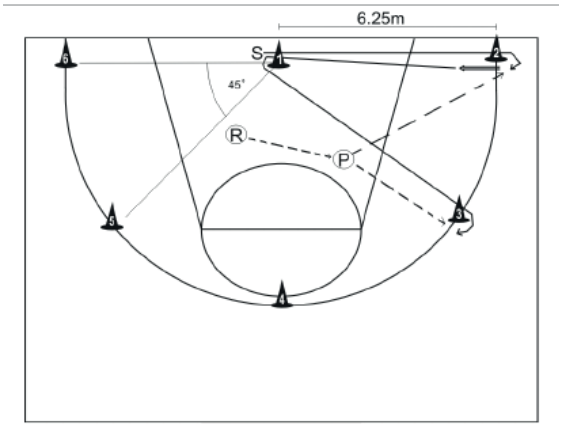
The study intervention took place at the Peak Performance Center (PPC), which is located in the sports sciences department of Yarmouk University. The Dynavision-D2 suggested intervention took place during the

general conditioning training session of the university basketball training and had no focus on game skills training. All sessions were scheduled in the morning (10 am–12 pm).

At the initial training session, researchers gave the participants a standardized script and verbal instructions on the training protocol; all training task protocols followed the instructions and recommendations of the manufacturer protocols of Dynavision™ D2 Visuomotor Assessment Device (D2; Dynavision International LLC, West Chester, OH). Researchers then addressed all their questions to familiarize them with the Dynavision D2 device. Then, the participants were asked to stand comfortably with an upright posture and balance (flexed knees, lowering center of gravity) in front of the Dynavision D2 board. The board was adjusted to the participant's height as instructed, the LCD screen was set approximately at the participant's eye level, and the outer-most target buttons were within hand reach. To ensure the board position, participants completed a practice trial along with verbal instruction. Training room conditions were standardized as temperatures were kept between 24-26 degrees and monitored by air conditioners and thermostats. Testing room lighting was also standardized for all participants across all sessions. The description of Dynavision-D2's suggested training program used is presented in Table 1, and practices were randomized.

Dynamic Three-Point Shoot Assessment

The accuracy of the dynamic three-point shoot was assessed using the widely used "90s dynamic three-point shooting" (Figure 1) assessment test protocol, which can be referred to (Zhang et al., 2023). In this assessment, participants are to shoot the 3-point shot from five marked positions around the three-point line as Pos1: Left Corner, Pos2: Left Wing, Pos3: Top of the Key, Pos4: Right Wing, Pos5: Right Corner. This setting is a real game scenario where players must reposition quickly to open shooting spots. The assessment is performed within 90 seconds. Furthermore, players have to stay dynamic between positions. Shooting accuracy is represented by calculating the percentage of shots made and the total points scored from all positions.



Note. The dynamic 90-second three-point shooting test (S3P60). R=rebounder; P=passer; S=shooter.

Figure 1. Dynamic 90-second three-point shooting test accuracy

Kinematic Analysis

The selected kinematic variables of the three-point basketball shot were analyzed using Dartfish software (Dartfish v5.0.1.0; Dartfish, 2020). The measurement procedures followed previously established basketball shooting kinematic protocols (Alexander & Hayward-Ellis, 2016; Ammar et al., 2016; Cabarkapa et al., 2022; Kambič et al., 2022; Majed et al., 2012) and were conducted in accordance with the operational guidelines described in the Dartfish User Guide (Dartfish, 2020).

Prior to data collection, a two-dimensional (2D) direct linear transformation (DLT) calibration was performed for the video camera to ensure spatial accuracy in angle measurement. A calibration frame with known vertical and horizontal dimensions was positioned within the shooting area and recorded before each session to establish scaling and minimize parallax error. For the kinematic analysis, the performance of the 3-point shot from position (3) (Top of the Key) was selected for analysis due to the convenience of video recording, and the average of two shots was statistically analyzed as most of the players were able to achieve at least two successful 3-point shots. Otherwise, the successful 3-point shot was kinematically analyzed. The researcher ensured the player performed the shot naturally to capture realistic kinematic data. The recorded performance videos were then imported into the Dartfish software. Dartfish's tracking and analysis tools were used following the software protocol to mark and analyze the key points. To calculate the selected Kinematic Variables of the 3-point basketball shoot, the following angles were defined as described in Table 2.

Table 2. Definitions of Kinematic Variables for the 3-Point Basketball Shot

Variable	Definition
Shoulder Flexion Angle	Angle between the trunk (torso) and the upper arm (humerus).
Elbow Flexion Angle	Angle between the upper arm (humerus) and the forearm (radius/ulna)
Wrist Flexion/Extension Angle	Angle between the forearm and the hand (metacarpals)
Hip Flexion Angle	Angle between the trunk (torso) and the thigh (femur)
Knee Flexion Angle	Angle between the thigh (femur) and the lower leg (tibia/fibula)
Wrist Extension Angle	Angle of wrist extension during the shot
Ball Release Angle	Angle of the ball's trajectory relative to the horizontal at the moment of release

The performance phases were defined in constant with previous literature as follows: Preparation Stage: This stage involves the setup and body positioning before the initiation of the shooting motion. During this phase, key kinematics include: Knee Flexion Angle, Hip Flexion Angle, Shoulder Flexion Angle, and Elbow Flexion Angle. Execution Stage; is the dynamic phase when the shooter initiates and completes the upward movement of the shot. In this stage, variables include: Knee Flexion Angle, Hip Flexion Angle, Shoulder Flexion Angle, Elbow Flexion Angle, and Wrist Extension Angle. Follow-Through Stage After the ball is released, continue the motion and help stabilize the shot. The primary kinematics are: Wrist Flexion Angle and Ball Release Angle.

Statistical Analysis

Statistical analyses included descriptive statistics (means and standard deviations) and paired-samples t-tests to evaluate pre–post differences in dynamic three-point shooting accuracy following the short-term Dynavision D2 training program. Effect sizes for within-subjects comparisons were calculated as Cohen's d_x using the formula $d_x=t/\sqrt{n}$. Simple linear regression analyses were conducted to examine the association between changes in kinematic variables (predictors: knee, hip, shoulder, elbow, and wrist joint angles, and ball-release angle) and

changes in shooting accuracy (outcome variable). The regression analyses served to elucidate which kinematic modifications most effectively accounted for enhancements in performance. Coefficients of determination (R^2) were interpreted as the proportion of variance in shooting accuracy explained by each kinematic variable. All statistical analyses were executed utilizing IBM SPSS Statistics for Windows, Version 20.0 (IBM Corp., Armonk, NY), with a level of statistical significance established at $\alpha=0.05$.

Results

The study employed a paired samples t-test and regression analysis to evaluate the effectiveness of the Short-Term Dynavision-D2 Training Program on basketball players' three-point dynamic shooting accuracy and kinematic variables.

Shooting Accuracy Improvement:

A paired samples t-test revealed a statistically overall significant improvement in three-point shooting accuracy from pre-training to post-training with a large calculated effect size (d=1.61), indicating that the training program had a substantial impact on shooting accuracy. These results are shown in Table 3.

Table 3. Paired Samples t-Test Results for Pre-Training and Post-Training Accuracy

Variable	M (Pre)	SD (Pre)	M (Post)	SD (Post)	t	df	p	Cohen's d
Accuracy (%)	15.7	2.16	18.2	2.10	6.23	14	<.001	1.61

Kinematic Performance Analysis:

Simple linear regressions were performed to define which kinematic variables best predicted improvements in shooting accuracy following the Dynavision-D2 intervention, key variables: Wrist Extension Angle, and Ball Release Angle. However, no statistically significant effects were observed for other kinematic assessed variables, results shown in Table 4.

Table 4. Regression Analysis of Kinematic Variables of 3-point Basketball Shooting Performance Pre and Post Training on the Short-Term Dynavision-D2 Training Program

Variable	t	β	R^2	F	p
Knee Flexion Angle	-0.374	0.078	0.008	0.138	.710
Hip Flexion Angle	-0.858	0.188	0.038	0.729	.418
Shoulder Flexion Angle	0.465	0.126	0.019	0.249	.629
Elbow Flexion Angle	1.08	0.247	0.066	1.157	.294
Wrist Extension Angle	-3.353	0.626	0.388	10.946	.004*
Wrist Flexion Angle	0.863	0.199	0.040	0.746	.399
Ball Release Angle	-2.856	0.401	0.161	8.158	.050*

Note. N=15. Significant p-values are indicated with an asterisk (*p<0.05).

Moreover, the results revealed that the Wrist Extension Angle accounted for 38.8% of the variance in performance improvements with a large effect size ($f^2=0.634$). Ball Release Angle accounted for 16.1% of the

variance with a medium effect size (f^2=0.192). The current results could highlight the role of athlete-specific kinematic adjustments during visual–perceptual training, suggesting that players who exhibited greater refinements in wrist extension and release mechanics achieved higher gains in shooting accuracy (see table 5 and figure 3).

Table 5. Kinematic Variables of the 3-Point Shooting Basketball Performance Before and After Training on the Short-Term Dynavision-D2 Training Program

Stage of Performance	Condition	Variable	Min	Max	Mean	SD
Preparation	Post-Training	Knee Flexion Angle	109.3°	116.2°	112.75°	1.99°
		Hip Flexion Angle	161.1°	166.6°	163.85°	1.59°
		Shoulder Flexion Angle	68.4°	77.1°	72.75°	2.51°
		Elbow Flexion Angle	65.6°	75.4°	70.50°	2.83°
	Pre-Training	Knee Flexion Angle	91.5°	125°	108.25°	9.67°
		Hip Flexion Angle	134.8°	140.2°	137.50°	1.56°
		Shoulder Flexion Angle	56.23°	67.2°	61.72°	3.17°
		Elbow Flexion Angle	42.9°	69.8°	56.35°	7.76°
Execution	Post-Training	Knee Flexion Angle	143.4°	162.6°	153.00°	5.54°
		Hip Flexion Angle	175.2°	185.97°	180.59°	3.11°
		Shoulder Flexion Angle	118.2°	120.8°	119.50°	0.75°
		Elbow Flexion Angle	144.4°	161.83°	153.12°	5.03°
		Wrist Extension Angle	133.6°	142.7°	138.15°	2.63°
	Pre-Training	Knee Flexion Angle	134.60°	152.85°	143.73°	5.27°
		Hip Flexion Angle	175.70°	179.45°	177.58°	1.08°
		Shoulder Flexion Angle	94.17°	115.80°	104.99°	6.25°
		Elbow Flexion Angle	145.60°	154.23°	149.92°	2.49°
		Wrist Extension Angle	135.77°	157.37°	146.57°	6.24°
Follow-Through	Post-Training	Wrist Flexion Angle	132.7°	148.5°	140.60°	4.56°
		Ball Release Angle	52°	58.6°	55.30°	1.91°
	Pre-Training	Wrist Flexion Angle	126°	135.5°	130.75°	2.74°
		Ball Release Angle	40.40°	53.40°	46.90°	3.75°

Note. Min=Minimum value; Max=Maximum value; SD=Standard Deviation. All data are representative as angles in degrees (°).

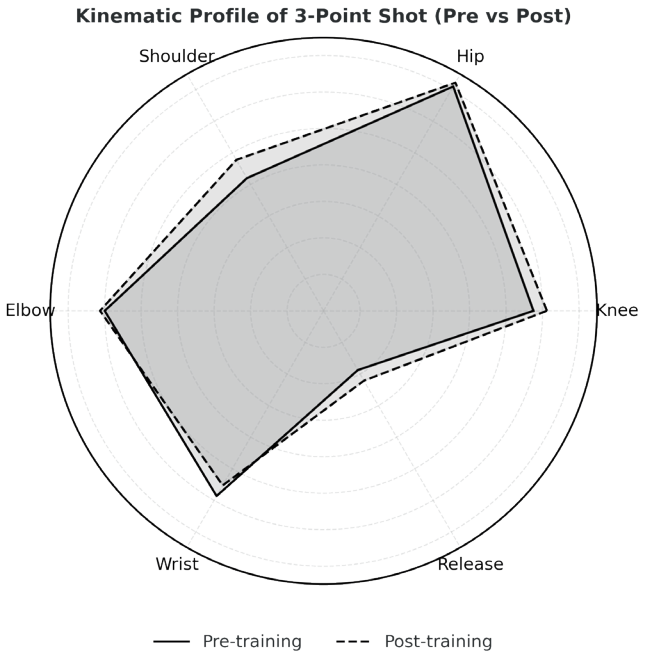


Figure 3. Kinematic profile of joint angles during the shooting sequence pre- and post-training. Solid line represents pre-training, dashed line represents post-training. Shaded areas indicate SD range.

Discussion

This study examined the effect of a short-term perceptual training program using the Dynavision D2 on dynamic three-point shooting accuracy and related motor performance variables in semi-professional basketball players. The results confirm that short-term training with the Dynavision D2 enhanced dynamic shooting accuracy, which may be related to post-training modifications in key kinematic parameters such as release angle and wrist extension—that reflect improved coordination rather than static or universally optimal movement patterns. Literature has emphasized that task related kinematic adaptations are player-specific and may not follow the optimal model. The most effective shooting performance kinematics, such as ball release angle or wrist angles, depend on an athlete's anthropometric characteristics, underlying technique, and situational context. Which highlights that improvement is better defined by consistency and adaptability rather than fixed numerical values (Cowin et al., 2022; Ammar et al., 2025).

The current study results support the integration of cognitive-motor training tools like Dynavision-D2 into basketball routines to boost performance, aligning with prior research emphasizing the benefits of such training on athletic capabilities (Jin et al., 2020; Lu et al., 2020; Sirnik et al., 2022; Zhao et al., 2024). It is worth noting that researchers focused on a within-subjects design in integrating the Dynavision D2 assessments, allowing players to track their individual progress. However, the absence of a control group might limit the generalizability of the current study results.

A comparable study by Lucia et al. (2023) found that fifty-two semi-professional players who completed cognitive-motor training showed a 13% greater performance improvement than those undergoing standard training, particularly in decision-making and response execution. Similarly, this study observed a statistically significant improvement ($p<0.05$) in shooting accuracy after the Dynavision-D2 intervention. These findings suggest that the program enhanced key skills such as coordination, visuomotor integration, and decision-making under dynamic conditions. The training included modules focused on reaction time, endurance, and proactive/reactive responses, all of which likely contributed to the observed performance improvements, supporting the study's hypothesis. By improving visual fixation, players can better plan and adjust motor actions in real-time, which is crucial during high-pressure situations in basketball (Blackwell et al., 2020; Wells et al., 2014). These findings align with Feldhacker et al. (2019), who demonstrated that Dynavision-D2 offers more effective proactive training than non-technological methods for collegiate softball athletes. Similarly, Aitcheson-Huehn et al. (2024) found that visual fixation before initiating motor actions significantly improved basketball shot accuracy. Their machine learning-based study, involving 12 players and 200 shots from six court locations, reported that fixation durations beyond 18% could enhance shooting success.

This study also supports earlier research linking superior shooting performance to strong perceptual and visual skills (Vickers et al., 2019; Ji, 2020; Uludağ et al., 2021; Huang & Liu, 2022). Enhanced visual perception contributes to improved shooting mechanics, including joint angles, smoother movements, and better upper-lower body coordination (Appelbaum & Erickson, 2018; Laby & Appelbaum, 2021; Lochhead et al., 2024). Current study linear-regression analysis revealed significant improvements in some shooting kinematics after the Dynavision-D2 intervention: wrist extension angle ($T=–3.353$, $p=0.004$, $R^2=0.388$) and ball release-angle ($T=–2.856$, $p=0.05$, $R^2=0.161$), These regression findings indicate that players who developed more coordinated wrist and release mechanics achieved greater improvements in accuracy, suggesting that perceptual–motor training with the Dynavision D2 can be effectively integrated into coaching practice. It could also be important to interpret these biomechanical adaptations as distinctive performance adjustments rather than as references to an optimal fixed model. Merging from individual constraints, experience, and coordination tendencies.

Comparable results were found by Lucia et al. (2024), who integrated cognitive training into physical sessions for professional and semi-professional basketball players, reporting improvements in sprint agility and motor preparation after just five weeks. Additionally, previous studies have shown that top scorers in free throws demonstrated superior proprioception, with strong correlations between wrist and elbow joint positions and shooting success (Oks et al., 2019; Sevrez & Bourdin, 2015). Zhen et al. (2015) also noted that during one-handed shooting, the ball is released when the legs are fully extended, and guidance is primarily controlled by the index finger, further confirming the importance of precise biomechanics. Similarly, França et al. (2022) used Dartfish-based kinematic analysis to emphasize the importance of shooting arm positioning, supporting the current study's conclusions. In summary, the success of this short-term intervention can be attributed to the Dynavision-D2's cognitive-motor skills (proactive/reactive) training. With its user-friendly interface and practical design, the Dynavision-D2 proves to be a valuable tool for basketball coaches aiming to improve player accuracy and reaction speed.

Conclusion

In conclusion, the Short-Term Dynavision-D2 Training Program significantly enhances three-point shooting accuracy and some kinematic variables in basketball players. These findings provide compelling evidence for the integration of cognitive-motor training tools into basketball practice, paving the way for further research and practical applications in sports performance enhancement.

This study contributes to the literature on sports skill training by exploring the effect of electronic training devices on shooting accuracy in basketball. It advances understanding of the role of coordination, visuomotor skills, and decision-making in shooting performance, highlighting the potential of Dynavision-D2 as a tool to improve these abilities. The study also contributes to the field of physical education and sports coaching by demonstrating the effectiveness of this type of program in improving shooting accuracy and overall fitness levels. Practically, the current study provides evidence-based support for the use of Dynavision-D2 in basketball training programs. Basketball coaches and trainers can address these findings to incorporate this device into their off-season training regimens to enhance three point shooting accuracy. The simple setup and user-friendly interface of Dynavision-D2 make it easily applicable in training environments, making it practical for a wide range of athletes. Despite its benefits, there are limitations of this study that should be acknowledged. The primary limitation is the relatively small sample size of 15 male basketball players and the absence of a separate control group, which may limit the generalizability of the results to a broader population. Additionally, the study was conducted over a relatively short time frame, spanning three weeks, which may not fully capture the long-term effects of the Dynavision-D2 program on player performance. Future research should examine the sustainability of these improvements over extended periods and across diverse athletic groups.

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EFFECT OF SPORTS ACTIVITY ON THE HEALTH OF FEMALE STUDENT ACCORDING TO BLOOD LIPIDS

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[A]Study Design; [B]Data Collection

Abstract Blood lipid analyses were conducted on athletes and non-athletes to determine the extent to which certain blood parameters are affected by sports activity. The research objectives included identifying the results of blood fats for students in the Physical Education Department and comparing them with those of students in the Chemistry Department. The descriptive approach was used to suit the nature of the study , while the research sample was a group of female students from fourth-year students in the Department of physical Education, College of Education for Girls (athletes), and female students from the fourth year of the Department of Chemistry (non-athletes), with 10 female students from each department . Note that the mean age of the students was 23.15 years, SD=0.67, median 23, the mean height was165 cm, SD=5.36, median 166, and the mean weight was 67.2 kg, SD=3.54, median 67. Blood samples were taken for each female student during break time in order to analyze five blood indicators to identify the extent to which physical activity affects these indicators was determined by comparing the two groups using statistical analysis. The results were then discussed. In light of the findings, the researcher drew several conclusions. Regular physical activity is essential for female students, regardless of their university major, and should be practiced two to three times per week to be effective for general health and obesity prevention, and to help regulate blood lipid and lipoprotein levels, as it influences fat accumulation in the blood and subcutaneous tissue. Diet determines fat intake ,while exercise helps regular lipid levels. It is recommended to conduct periodic blood lipid tests for athletes and non-athletes alike to identify a person's health status early.

Key words: sports activity, athletes, non-athletes, blood lipides

Introduction

Physical activity decreases the risk of developing or dying from different cardiovascular diseases, not least because physical activity can partly prevent or slow the development of high blood pressure (Fuchs & Whelton, 2020). These achievements, which reflect this great development in the field of sports, especially during the past few years, were only the result of scientific development and its applications in sports aspect. Today, we are in dire

need of making more efforts to achieve sustainable progress that ensures for the sports movement a noticeable and broad, advanced progress on various levels, believing that scientific progress is the basic link that connects research findings correctly to form a harmonious chain based on studies and research. With respect to physical activity, organ system responses and adaptations typically determine the fitness level of the body (Ziauddin & Fagundes, 2023).These changes are of two types: temporary changes, meaning changes that occur temporarily in response to physical activity, but blood returns to its normal state at rest (Buyukyazi et al., 2010) and relatively permanent, meaning changes that occur in the blood as a result of training Exercise has a significant impact on blood components. For example, hemoglobin levels can increase by 1–2 g within months of regular training. Blood pH typically ranges between 7.35 and 7.45, and although intense exercise causes slight changes in acidity, the body quickly regulates this balance. Red blood cell (RBC) count can increase by approximately 10–20% in athletes who regularly engage in endurance training (Szymanowski et al., 2020; Shamaitijiang et al., 2024) Using blood lipid tests for athletes and non-athletes greatly helps to identify changes that occur in a person's blood during rest and physical exertion in both athletes and non-athletes. Studies using these tests and to compare athletes with non-athletes provide valuable insights (Bull et al., 2020).They indicated that physical activity stated that p affects individual health based on blood parameters, and the mechanism for developing and improving these components to serve the individual's health and avoid the risk of disease .

Blood is an important physiological indicator for athletes and non-athletes alike (Izadifar et al., 2017). Understanding the biological effects of this variable provides valuable information for professionals in the sports field, particularly regarding blood pressure regulation. It also serves as an important reminder to non-athletes of the benefits of engaging in regular physical activity The research problem lies in the significant lack of adherence to regular and scheduled medical examinations of blood indicators for most female students compared to developed countries, in addition to the lack of awareness among female students of engaging in physical activities to improve the health indicators from the perspective of blood lipids. Therefore, the researchers decided to study This study aims to explore the positive and negative effects of exercise on blood components in individuals.

The study aimed to evaluate certain blood indicators in students from the Department of Physical Education and Chemistry (Qiu et al., 2023) and to assess the impact of exercise on the health of female students. The findings indicate that participation in athletic activities has a positive effect on the health of female athlete.

Research Methodology

The researcher used the descriptive survey method, as it is appropriate approach to addressing the research problem (Fricker Naval, 2022)

Research Sample

The researchers' objectives for the study and the procedures used determine the nature of the sample chosen. The sample was selected from applications from the University of Kufa / College of Education for Girls / Department of Physical Education and Sports Sciences and Chemistry Department, with a number of ten from each department, and the students were chosen randomly. This sample represents 33% of the original population, noting that the number of fourth-year students was for the academic year 2024/2025 is (30), (31) students in the Sports and Chemistry departments, respectively..The mean age of the students was 23.15 years, sd.0.67, median 23, the mean height was 165 cm, SD=5.36, median was 166, and the mean weight was 67.2 kg, SD=.3.54, median was 67.

Research tools and equipment are the means by which researchers collect data and address the research problem to achieve the study objectives, regardless of the specific tools or equipment used:

- A 2mL medical syringe with (25 syringes);
- A turntable;
- 25 blood storage tubes (EDTA), manufactured in Jordan;
- Medical cotton with antiseptic solution for sterilization;
- Physical fitness lab at the College of Education for Girls.

Research Field Procedures

On February 9, 2025, the researchers met the randomly selected sample from the two departments (Physical Education and Chemistry). Approval was obtained from Professor Dr. Hamida Obaid Abdul Amir, Head of the Department of Physical Education and Sports Sciences, and Professor Dr. Faiz Al-Ramahi, Head of the Department of Chemistry, to collect blood samples from the selected female students . The participants were informed about the objectives of the study, the overall research purpose, and their roles and responsibilities as participants in the study (the students' verbal consent was obtained). The date was set for February 17, 2025. To conduct the analysis of the sample, blood samples of 2 cc were drawn, and the blood samples were transferred directly to the hematology laboratory after collection at Al Sadr Teaching Hospital (approval was obtained from Dr. Lina Arear, head of the blood analysis laboratory)to conduct the analysis and extract the results.

Exploratory experiment

The experiment was conducted on February 13, 2025, on two fourth-year students from the Chemistry Department and two students from the Sports Department. Blood samples were collected from the students during their break, and blood transfusion procedures were monitored. The procedure for transfusion to the laboratory at Al Sader Hospital and the hospital's hematology laboratory were monitored to ensure that all variables that may accompany work were controlled. In light of the exploratory experience the researchers were able to identify the following;

A. The extent of the students' understanding and comprehension of the test vocabulary.
B. Verifying the validity of the tools and equipment used.
C. Obstacles faced by the researchers when conducting the test, with the aim of overcoming them.
D. The number of the team assisting in implementing the test.
E. The time required to conduct the test..

Results

Presentation and Analysis of Blood Fats

Table 1. Results of blood test measurements of lipoproteins (LDL, HDL, vLDL), as well as lipids (Total Cholesterol, STG) for the study sample.

A- Physical Education Department

Tests	LDL mg/dl	HDL mg/dl	vLDL mg/dl	Total Cholesterol mg/dl	TG mg/dl
1	73	52	14.4	139	72
2	42	49	10.8	101	54
3	72.8	60	23.2	156	116
4	75.8	58	11.2	145	56
5	83.6	66	22.4	172	112
6	60.6	58	13.4	132	67
7	74.2	74	30.8	179	154
8	61	62	18	141	90
9	99	68	13.6	180	68
10	89	66	14.3	169	71.5

B- Chemistry Department

Tests	LDL mg/dl	HDL mg/dl	VLDL mg/dl	Total Cholesterol mg/dl	TG mg/dl
1	84.2	45	36.8	166	184
2	97	41	24	162	120
3	65	46	35	146	175
4	98	51	26	175	130
5	77.6	53	14.4	145	72
6	79	60	33	172	165
7	90.2	43	30.8	164	154
8	78.4	56	37.6	172	188
9	68.8	61	35.2	165	176
10	60.8	42	37.2	140	186

*-The normal ranges of lipid profile components, are as follows: LDL 108–188 mg/dl, .HDL (Low level <40 and High level ≥60) mg/dl), VLDL (<38 mg/dl), Total Cholesterol (150–200)mg/dl, Serum Triglycerides (35-160) mg/dl.

Table 2. Mean, standard deviation, calculated and tabulated t-value, and statistical significance of the blood lipid variables for the study sample.

Tests	Chemistry		Sport		t	Sig.
	X	SD	X	SD		
LDL	79.9	12.74	73.1	16.02	1.050	0.308
HDL	49.8	7.46	61.30	7.54	3.427	0.003
VLDL	31	7.47	17.21	6.40	4.430	0.000
Total Cholesterol	160.7	12.51	151.4	24.84	1.057	0.309
TG	155	37.37	86.05	32.02	4.430	0.000

Degrees of freedom =18, and a margin of error (0.05).

All research variables showed statistically significant differences, as the sig. value was less than the significance level of (0.05), except for LDL and cholesterol, where the sig. value was greater than the significance level of (0.05).

Discussion

Discussion of Blood Lipids

Low-density lipoproteins (LDL)

The results showed that female chemistry students had higher levels of LDL in their blood samples (79.9 mg/dl) compared to female physical education students (73.1 mg/dl), but this difference was not statistically significant and all values were within normal ranges. These proteins play an important role in transporting cholesterol from the liver to the body's various cell tissues, building cell membranes and producing specific hormones. An increase in the levels of these proteins is considered a risk factor (Markin et al., 2023), serving as an indicator of atherosclerosis due to the accumulation of cholesterol and low-density lipoproteins on the inner walls of the arteries.

The slight decrease in the levels of these proteins in the blood of female physical education students, compared to the arithmetic mean, is an indication of the role of exercise and physical activity in reducing the risk of atherosclerosis Atherosclerosis is prevented by lowering LDL levels. This reduces the likelihood of high blood cholesterol levels, as exercise helps the body consume energy and prevents it from accumulating as fat in the blood .

The LDL level can be calculated using the following equation:

LDL=TC – HDL - (Triglyceride / 5) (Wilson et al., 2021).

- TC Total cholesterol level.
- HDL High density cholesterol level.
- Triglyceride level.

High-density lipoproteins (HDL)

Atherosclerosis is known to be aided by dyslipidemia (hypercholesterolemia, hypertriglyceridemia, elevated low-density lipoprotein (LDL-C) levels, and/or reduced high-density lipoprotein (HDL) (Doewes et al., 2023).

The results showed that female physical education students had statistically higher HDL levels in their blood (61.30 mg/dl), compared to female chemistry students (49.4 mg/dl). These proteins play an important role in removing excess cholesterol from various body tissues and return it to the liver for excretion. High-density lipoproteins are

believed to prevent cholesterol from accumulating on the inner walls of the arteries, thereby protecting against atherosclerosis (Jebari-Benslaiman et al., 2022).

The proportion of these proteins is affected by several factors, including genetics, exercise, gender, and nutrition. The high level of these proteins in the blood of female physical education students indicates the role of exercise and sports in reducing the risk of atherosclerosis (Barnard et al., 2019).

Very low-density lipoproteins (VLDL)

The results showed that female chemistry students had a statistically higher levels of VLDL in their blood (31 mg/dl) compared to female physical education students (17.21 mg/dl). This is because these proteins play an important role in carrying and triglycerides (resulting from increased consumption of starchy and sugary foods and excess calories) from the blood. The liver stores them in fat cells distributed throughout the body (Huang & Lee, 2022).

High levels observed in chemistry students indicate elevated blood triglycerides, which reflect the conversion of excess sugars and starches into stored fat within adipose cells when they are not utilized for energy production A continued rise in triglyceride levels is considered a significant risk factor for atherosclerosis. Regular exercise greatly helps reduce fat accumulation on the inner walls of the arteries, thereby lowering the risk of arterial narrowing, heart attacks, and strokes. Al-Khalidi, Jasim & Takleef (2018) state that this practice helps the body consume energy, preventing its accumulation in the blood as fats, which is consistent with the results of the current study. Jasim & Takleef (2018) state this practice actually helps in consuming energy in the body and preventing for its accumulation in the blood as fats, for example, and this is what the results of the current study confirmed.

Discussion of the results of serum triglycerides (TG)

In the research sample, the results showed that female physical education students had a statistically lower serum triglyceride(TG)level level in their blood (86.05 mg/dl) compared to female chemistry students (155 mg/dl). The lower STG level in the blood of female physical education students was due to the positive effects of exercise (Al-Khalidi & Al-Ghazali, 2017) Triglycerides are small fat particles that constitute approximately 95% of the body's stored fats. Measuring blood triglyceride levels provides an indication of the number of these fat particles circulating in the bloodstream. When a person consumes excess carbohydrates that are not used for energy, the surplus is converted into triglycerides. If these triglycerides are not utilized for energy production, the excess is stored in fat cells distributed throughout the body. The entire body (abdominal area, thighs, arms, neck, etc.) has been found to be linked to atherosclerosis (Libby et al., 2022).

Sultana et al. (2015) reported that triglyceride (TG) levels in their sample were within the normal range established by the World Health Organization (WHO).

Discussion of cholesterol results

The results showed that the blood cholesterol levels of the female physical education students were similar (151.4 mg/dl) compared to the female chemistry students (160.7 mg/dl), but did not show a statistically significant difference.

A close examination of the results reveals an increase in the blood cholesterol levels of the female chemistry students compared to the female physical education students, but this was not significant enough to indicate a statistical difference.Blood cholesterol levels in normal cases ranges between 150–200 mg/dl, and an increase

above this range is considered a dangerous indicator for the body of atherosclerosis and heart disease. As we notice that female chemistry students, through the results, showed the beginning of a rise in cholesterol levels, and these results demonstrates the importance of practicing physical exercise and regulating food to maintain a moderate percentage of cholesterol (Brun et al., 2018).

Conclusions

Exercising helps individuals regulate their blood lipids levels, which positively impacts their health. Regular physical activity is essential for female students, regardless of their university major, and should be practiced 2–3 times per week to be effective in general health and fitness, and to help regulate blood lipid and lipoprotein levels, as it has implications for fat accumulation in the blood and under the skin. Studies have shown that cholesterol and LDL are not significantly affected by exercise, while TG, HDL, and VLDL are significantly and directly affected. Exercise, along with a balanced diet, is best for regulating blood lipids and maintaining a healthy body. The amount of fat entering the body depends on diet, but exercise can help regulate it. Furthermore, periodic monitoring of blood lipid levels is recommended for both athletes and non-athletes to identify a person's health status at an early stage.

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EFFECT OF AEROBIC FITNESS ON CARDIO-VAGAL ADAPTATION

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Abstract Introduction: Maximal oxygen consumption (VO_2 max) and heart rate variability (HRV) are important physiological indicators of both cardiovascular fitness and autonomic nervous system regulation in exercise science. This study aimed to examine the effect of aerobic fitness on cardio-vagal adaptation in young adults. Methods: Thirty-five physically active university students (23.89±1.64 years), with a minimum of four years of regular exercise participation were included in this study. VO_2max was assessed using a graded treadmill test and HRV indices were obtained from ECG recordings using LabScribe and Kubios software. Pearson's correlation with Bonferroni-adjusted was performed for statistical analysis. Results: No significant correlations were observed between VO_2 max and time-domain HRV indices SDNN(r=0.177, p=0.309); pNN50(r=0.198, p=0.254) and NN50(r=–0.340, p=0.846), while RMSSD(r=0.340, p=0.045) showed weak to moderate positive association. In contrast, significant correlations were found with frequency-domain indices, including HF power (r=0.450, p=0.006) and LF power (r=–0.450, p=0.006) and LF/HF ratio (r=–0.449, p=0.006). Conclusion: These findings indicate that regular aerobic exercises associated with improved parasympathetic modulation and enhanced cardio-autonomic balance in young adults.

Key words: cardio autonomic function, graded exercise protocol, heart rate variability, parasympathetic tone, VO2max

Introduction

According to the World Obesity Atlas 2024 published by the World Obesity Federation, it is projected that by 2035, over 1.77 billion individuals will be classified as overweight, while 1.53 billion will face obesity. This will account for 54% of the global adult population (Janić et al., 2025). Insufficient physical activity is recognized as the primary contributor to this obesity and is also a significant factor in mortality rates. In light of the recent increasingly prevalent technology-driven lifestyle, the rates of obesity continue to rise each year (Mittal et al., 2022).In this respect regular physical activity (PA) can be a non-pharmacological mediator for reduced obesity and improved cardiorespiratory fitness (CRF). The enhancement of CRF or aerobic fitness (VO2Max) for physical well-being through PA has been noted and documented in physically active individuals with normal weight (Chen et al., 2019; Alansare et al., 2021; Masroor et al., 2018).

An individual's physical as well as mental well-being is influenced by the proper release of hormones and a balanced autonomic nervous system. Any existing cardiometabolic issue disrupts the typical functioning of cardiac autonomic functioning (CAF) in the body, which can have health consequences (Oliveira et al., 2020; Silva et al., 2017; Rossi et al., 2015). Evaluating CAF through heart rate variability (HRV) assessment is considered a straightforward, non-invasive, and dependable approach (Ziemssen & Siepmann, 2019; Catai et al., 2020), and aerobic fitness is a crucial factor in sustaining cardiac autonomic health. While VO2 max (the maximum amount of oxygen consumed) is considered the premier assessment tool for CRF (Zoolaktaf, 2007), heart rate variability (HRV) measures the variation in time between successive heartbeats, which arises from an integrated regulatory system responding to various psychological and environmental stresses (Shaffer & Ginsberg, 2017). Engaging in regular aerobic training or exercise results in both structural and functional adaptations in the cardiovascular system, which may influence HRV measurements. These alterations are particularly beneficial in decreasing the likelihood of cardiovascular diseases and premature mortality, thereby positively impacting cardiovascular well-being and the operational state of the autonomic nervous system (ANS) (Sandercock et al., 2005; Hottenrott et al., 2006; Routledge et al., 2010).

Research studies have indicated that aerobic exercise programs can lead to an increase in heart rate variability (HRV) among healthy adults (Carter et al., 2003; Iwasaki et al., 2003; Tulppo et al., 2003). In line with this, various exercise interventions have been shown to improve HRV even in sedentary middle-aged individuals (Navarro-Lomas et al., 2022). A correlational study involving healthy young adults who did not engage in any rigorous physical activity demonstrated that VO2 max is linked to heart rate variability metrics (Saini et al., 2022)

While existing studies suggest that exercise boosts both VO_2 max and HRV, the relationship between these two elements in regularly active, non-clinical groups remains unclear. Therefore, additional investigation into how these factors interact is essential. Hence, the objective of the current study was to explore the relationship between VO2max and HRV indices in healthy young adults using a cross-sectional research approach.

Methods

Participants

The study was executed at Exercise and Sports Physiology Laboratory, Department of Physical Education, Jadavpur University, Kolkata, India. G*POWER software (Version3.1.9.7) was used for calculation of sample with effect size=0.50, α=0.05 and the power =0.85 (Faul et al., 2009; Kang, 2021). According to the G*POWER calculation

the required sample size (n) was at least 32. Thus, a total 35 adult youth subjects aged 23.89±1.64 were recruited in the present study. Prior to commencing the study, clearance from institutional ethical committee was taken (Ref No: IEC/37/C/25) and for the recruitment of the participants, researchers organized an orientation program to give detailed explanation about the study. All interested candidates were requested to complete the personal consent form, and ultimately participants were selected via purposive sampling to fulfill the study's objectives. The study was also approved by the Clinical Trial Registry of India (CTRI) with registration number CTRI/2025/05/086537.

Inclusion and Exclusion criteria

Male participants aged between 23.89±1.64 years with minimum four years' regular involvement in physical activity or exercise at least five days in a week for two hours each day were assigned as subjects in this study. All the participants were selected from Jadavpur University, stayed in the hostel thus followed same biological clock and diet pattern. Individuals with any chronic health conditions, injuries, or medical disorders were not considered in the present study.

Administration of Tests

Researchers assessed aerobic fitness using the Treadmill Test (TMT) based on the Bruce Protocol, employing a complete iworx system that included the IX-TA-220 acquisition unit, iWire-GA1 CO_2/O_2 gas analyzer with filter, a 3-liter calibration syringe, flow-head tubing with an A-FH-1000 flow head, an A-GAK-201 reusable mask, a 5-liter mixing chamber (A- GAA-MC), an A-CAL-200 calibration kit, and the PHRM-220 heart-rate monitor—all manufactured by iworx Systems Inc. (Dover, NH, USA). The Bruce Protocol, widely used to estimate cardiorespiratory fitness, consists of seven three-minute stages, each increasing in treadmill speed and incline, and is designed to determine maximal oxygen uptake (VO_2 max). For the assessment of VO2 max participant's preparation involved several phases. In first phase (resting/supine), the skin was cleaned and mildly abraded to ensure good electrode contact, following this preparation, ten ECG electrodes were positioned on the participant using the standard Mason–Likar placement illustrated in Table 1. The acquisition system was then connected, and a resting ECG was recorded along with baseline measurements including heart rate and blood pressure, typically taken while the participant was lying supine. In second phase consisted of a brief standing baseline, allowing comparison between supine and upright physiological values before exercise. In third phase, participants performed controlled hyperventilation while standing to differentiate respiratory-related ECG variations from possible cardiac abnormalities. After all initial data were collected, participants were briefed about the test procedure, safety instructions were reviewed, and the respiratory mask was fitted securely and checked for comfort and proper seal.

Once all preparations were completed, the treadmill test began following the automated Bruce Protocol. Participants started walking, progressing through the increasing stages of speed and incline every three minutes, the complete detail of which is given Table 2 below. When the participant's heart rate reached 85% of their maximum, the test was stopped, and LabScribe software (version 4.0) was used to generated the individual VO_2 max values and final assessment report.

Table 1. Placement of Leads for the Assessment of VO2 max.

Lead	Placement
RA (Right Arm)	Below right clavicle, on the outer edge of the chest
LA (Left Arm)	Below left clavicle, on the outer edge of the chest
RL (Right Leg, Ground)	On the lower right abdomen or right iliac crest
LL (Left Leg)	On the lower left abdomen or left iliac crest
V1	Fourth intercostal space at the right sternal border
V2	Fourth intercostal space at the left sternal border
V3	Midway between V2 and V4
V4	Fifth intercostal space at the midclavicular line
V5	At the same horizontal level as V4, at the anterior axillary line
V6	At the same horizontal level as V4 and V5, at the midaxillary line

Table 2. Stages, Speed and Inclines of Bruce Protocol.

Stage	Treadmill speed	Treadmill incline
1	1.7 mph	10%
2	2.5 mph	12%
3	3.4 mph	14%
4	4.2mph	16%
5	5.0 mph	18%
6	5.5 mph	20%
7	6.0 mph	22%

For the assessment of HRV from electrocardiogram (ECG) the researchers used iwire-B3G instrument through LabScribe software (version 4.0). Before the assessment, the participants relaxed for half an hour in a quiet room with a constant temperature. Then they were made to sit comfortably on an armchair keeping both legs on the wooden cube, three disposable ECG electrodes were fixed on the underside of the right and left wrist subsequently and on the right ankle as well. All electronic and metal items were cautiously taken away from the participants, and ECG signals were recorded for 25 minutes. From this, artifact-free 5-minute segments were selected for R–R interval extraction. During R–R interval processing, researchers used ECG data filtered within the 500–1000 Hz range (Malik et al., 1996). Finally, the R–R interval data were imported into Kubios HRV Standard software (version 3.5.0), which generated the time- and frequency-domain HRV analysis. Full details of HRV variables were provided in Table 3 below whereas Figure 1 illustrates the trial profile and outlines the primary outcome.

Table 3. Details of Time Domain and Frequency Domain Variable of HRV.

	Variables	Description	Units	Dominance
TIME DOMAIN	RMSSD	The Root Mean Square of Successive Differences between normal heartbeats	milli seconds (ms)	Parasympathetic dominance
	SDNN	Standard Deviation of the N-N intervals	milli seconds (ms)	Parasympathetic dominance
	NN50	Adjacent NN intervals differing by more than 50 milli seconds in the entire recording	numbers	Parasympathetic dominance
	pNN50	proportion of NN50 divided by the total number of NN intervals	percentage %	Parasympathetic dominance

	Variables	Description	Units	Dominance
FREQUENCY DOMAIN	LF power	Power in low frequency range	Milliseconds square (ms^2)	Parasympathetic dominance
	HF power	Power in high frequency range	Milliseconds square (ms^2)	Parasympathetic dominance
	LF/HF Ratio	Ratio LF [ms^2]/HF [ms^2]	percentage %	Sympathetic dominance

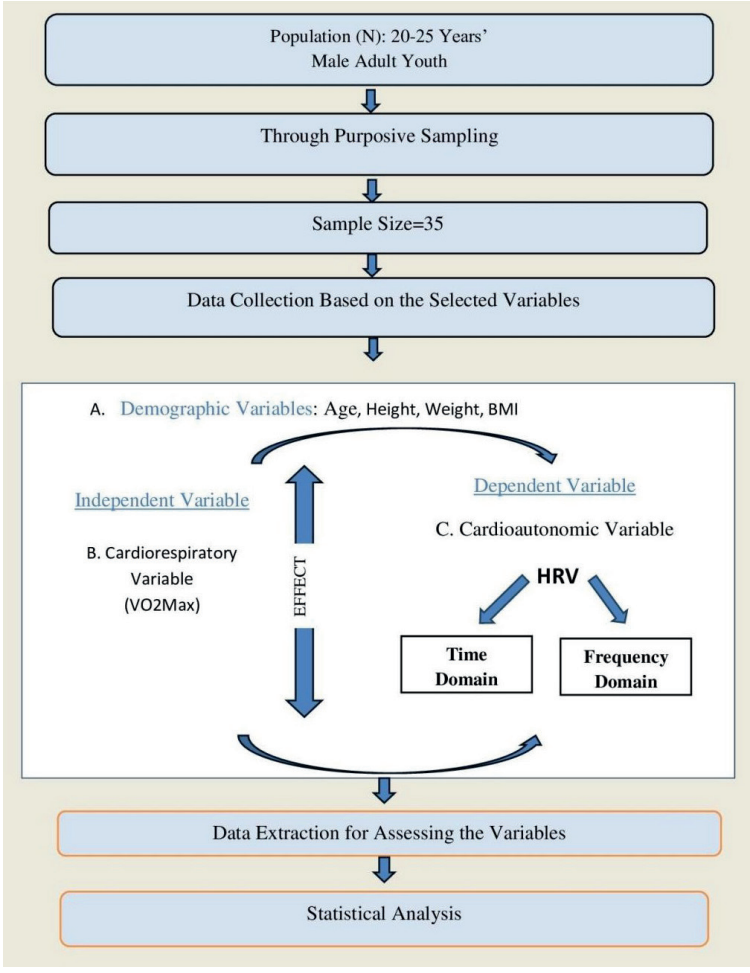


Figure 1. Flowchart of Trial Profile

Statistical procedure

Statistical analyses were performed using SPSS software (version 22.0). The normality of data distribution was assessed using the Shapiro–Wilk test, which confirmed that the data were normally distributed. Descriptive statistics were expressed as mean ± standard deviation. Inferential analysis was conducted using Pearson's product–moment correlation coefficient to examine the relationships between VO_2 max (independent variable) and

selected heart rate variability (HRV) indices (RMSSD, SDNN, NN50, pNN50, LF, HF, and LF/HF ratio) as dependent variables. To control for the increased risk of Type I error associated with multiple comparisons, Bonferroni correction was applied to adjust the significance threshold. The level of statistical significance was set at $p \leq 0.05$.

Results

The demographic characteristics of the 35 participants are presented in Table 4. Table 5 summarizes the Pearson correlation coefficients between VO_2max and selected HRV indices, including adjustments for multiple comparisons using the Bonferroni correction. In the time- domain analysis (Figure 2), VO_2 max showed a weak to moderate positive correlation with RMSSD (r=0.340, p=0.045). However, this correlation did not remain significant after applying the Bonferroni correction (adjusted α=0.007). Similarly, the other time-domain indices SDNN (r=0.177, p=0.309), NN50 (r=–0.340, p=0.846), and pNN50 (r=0.198, p=0.254) were not significantly correlated with VO_2 max, both before and after the Bonferroni adjustment. In contrast, in the frequency-domain analysis (Figure 3), VO_2 max showed significant relationships with several HRV indices even after Bonferroni correction. HF power was positively correlated with VO_2 max (r=0.450, p=0.006), indicating that higher aerobic fitness was associated with higher parasympathetic activity. LF power, on the other hand, was negatively correlated with VO_2 max (r=–0.450, p=0.006), indicating that higher VO_2 max was associated with lower sympathetic modulation. Similarly, LF/HF ratio (r=–0.449, p=0.006) was negatively correlated with VO_2 max indicates a shift towards a more balanced or parasympathetic-dominant state, suggesting improved stress recovery and relaxation. All these correlations remained statistically significant even after applying the Bonferroni-adjusted significance threshold of 0.007.

Table 4. Demographic characteristics of participants.

Variables	Mean±SD (n=35)
Age(Years)	23.89±1.64
Height(cm)	169.71±5.52
Weight(kg)	63.94±7.54
BMI	22.09±3.87

Table 5. Descriptive and correlational statistics between VO2 max and selected HRV indices with Bonferroni adjustment.

Independent Variable	Dependent Variable	Mean ± SD	Correlation coefficient (r)	p- value	Bonferroni-adjusted α	Significant
VO2 max (ml/kg/min)	SDNN(ms)	46.94±11	.177	.309	0.007	No
	RMSSD(ms)	49.10±12	.340	.045	0.007	No
	NN50(beats)	199.08±160.48	-.034	.846	0.007	No
	pNN50(%)	26.67±16.69	.198	.254	0.007	No
	LF Power(n.u)	47.19±13.48	-.450	.006	0.007	Yes
	HF Power(n.u)	52.67±13.42	.450	.006	0.007	Yes
	LF/HF	1.04±0.64	-.449	.006	0.007	Yes

Abbreviations: SDNN: standard deviation of the normal-to-normal sinus node-initiated R-R intervals; RMSSD: root mean square of successive R-R interval differences; NN50: Adjacent NN intervals differing by more than 50 milli seconds in the entire recording; pNN50: Proportion of differences in consecutive N-N intervals that are longer than 50 ms; LF: Low frequency; HF: High frequency; LF/HF: Low frequency by high frequency ratio; SD: standard deviation.

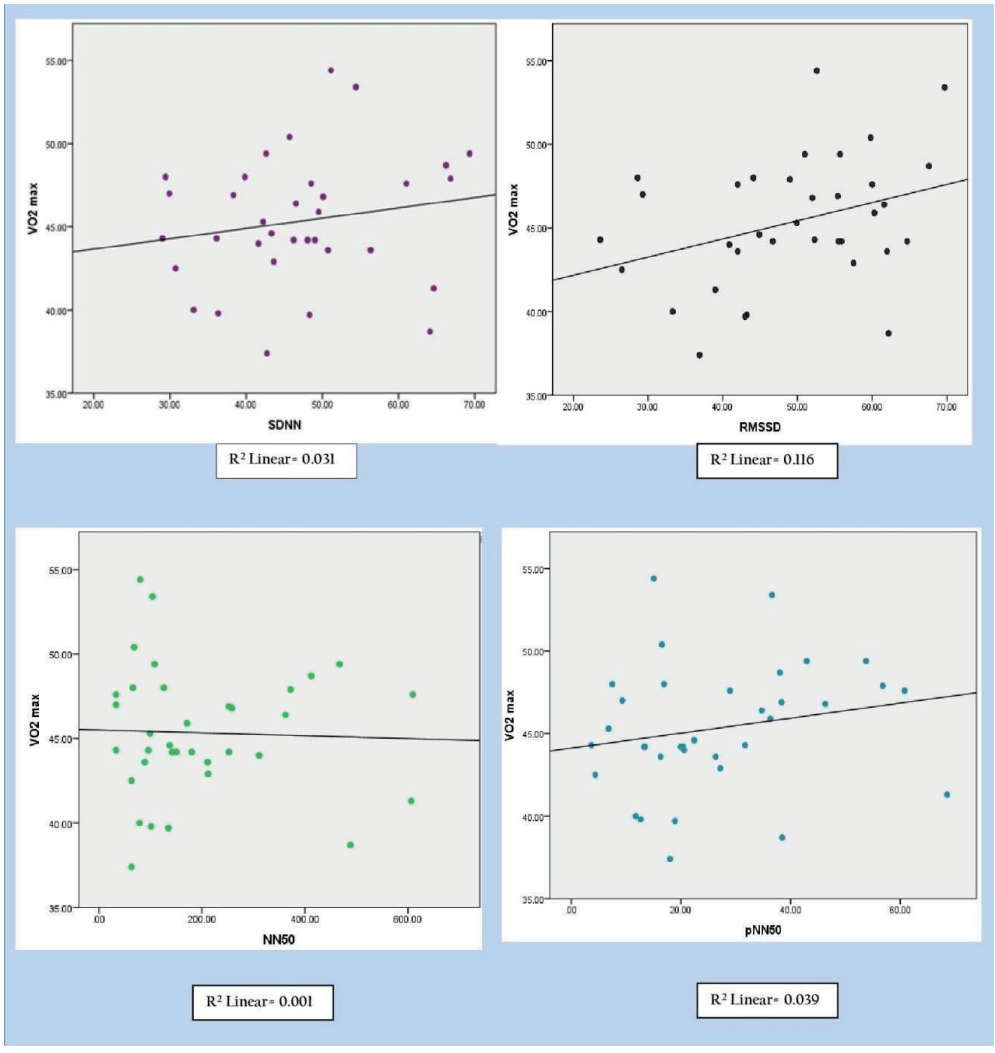


Figure 2. Scatter plot illustrating the correlation among VO2max and Time domain measures of HRV

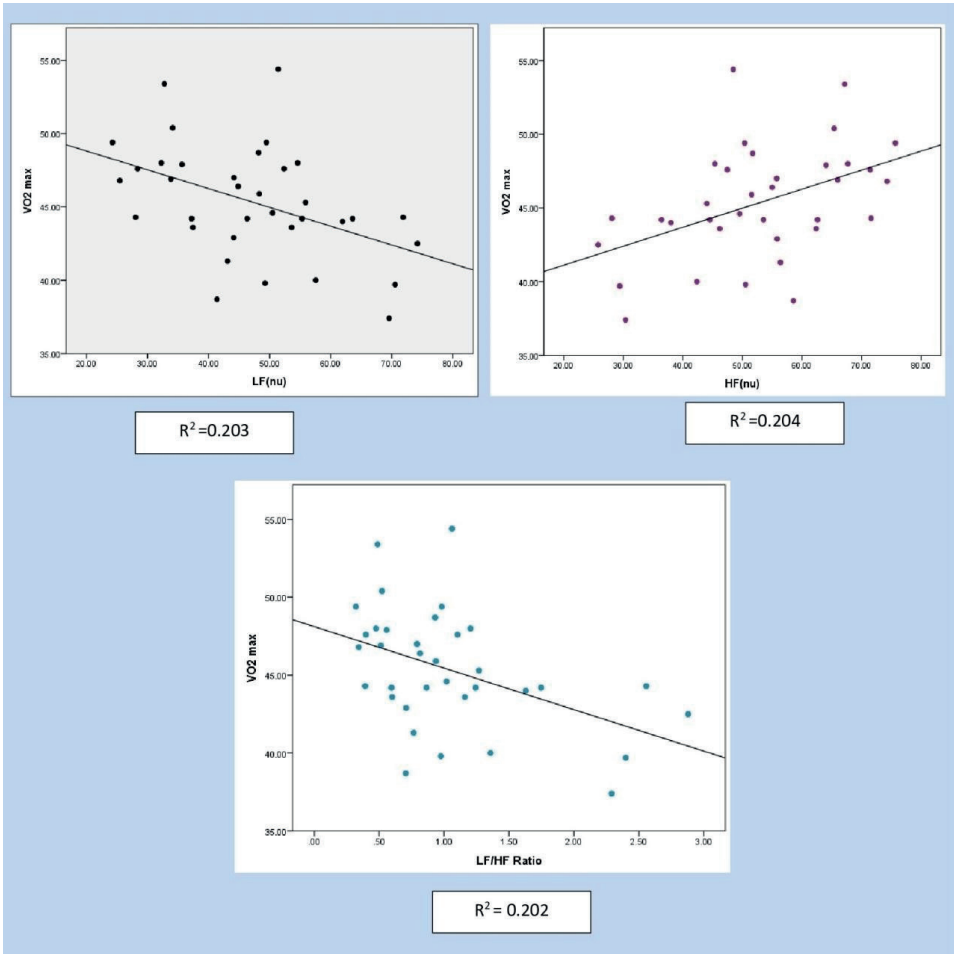


Figure 3. Scatter plot illustrating the correlation among VO2max and Frequency domain measures of HRV

Discussion

HRV time domain and frequency domain indices are related to cardiac electrophysiology and autonomic regulation, are indicative of healthier responses as the existing literature claim that regular physical activity has been associated with increased vagal modulation and reduced sympathetic activity (Swain & Franklin, 2005). This vagal modulation conforms to superior exercise capacity by exercise training which hails usually low resting heart rate. A longitudinal study conducted with a group of untrained young individuals also supported these findings, showing that 6 weeks of aerobic exercise training lowered resting heart rate and enhanced cardiac vagal tone, evaluated through HRV analysis (Al-Ani et al., 1996). Studies conducted on athletes (Daanen et al., 2012; Mann et al., 2014), patients with heart failure (Myers et al., 2007; Pearson & Smart, 2017; Streuber et al., 2006), and patients with Type 2 diabetes (Bhati et al., 2017) have demonstrated that exercise training accelerates heart rate

recovery, indicative of enhanced cardiac vagal function. The present study intended here to identify any correlation between aerobic fitness and HRV indices as the available literature has already found a positive correlation between superior exercise and training module with increased aerobic fitness (Wilmore & Knuttgen, 2003). More recent studies also reiterated similar aligned results as the present study. Zaki et al., 2024, showed similar results as of the present study on type two diabetic patients where a positive significant correlation was noted between VO2 max and RMSSD (Zaki et al., 2024). The relationship between the LF/HF ratio and VO2max in another study by Daniela et al., 2022, further supported the results of the present study and the overall notion that higher levels of fitness are associated with a more favourable autonomic balance (Daniela et al., 2022). A weak to moderate positive correlation between RMSSD and VO2max was noted in the present study, also suggested that higher cardiorespiratory fitness levels are associated with enhanced parasympathetic modulation as seen (Cabral et al., 2019). Our findings align with an earlier study by Camillo et al., 2011, which demonstrated that a 12-week high-intensity training regimen incorporating both endurance and strength exercises could enhance HRV measures, including RMSSD, HF and LF/HF (Camillo et al., 2011). Bor ghi-Silva et al., 2009 observed aerobic training program improved some of the time and frequency domain HRV indices (Borghi-Silva et al., 2009). While other time domain aspects SDNN, NN50, pNN50 found a scrawny relation with aerobic fitness. In frequency domains of HRV the researchers found positive significant relation of HF (n.u) with aerobic fitness tend to have stronger parasympathetic modulation of heart rate. This is a marker of good cardiovascular health and recovery capacity whereassignificant negative correlation was found between this resting LF/HF ratio and aerobic fitness which is associated with lower sympathetic dominance and greater parasympathetic activity. As the LF/HF ratio is often implied to be an index of the balance between sympathetic and parasympathetic system henceforth a higher ratio of LF/HF indicates a relative pre dominance of sympathetic activity unlike a lower ratio of LF/HF demonstrated improved cardio-vagal tone. These findings are consistent with research of Gilder & Ramsbottom, 2008 reported that aerobic exercise improves the resting ANS by reducing the sympathetic effect on the heart and boosting the parasympathetic influences (Gilder & Ramsbottom, 2008), similarly Tekin et al., 2025 was found the same result (Tekin et al., 2025). The mechanism of impact of aerobic fitness on cardio autonomic function which has been reflected in the results of the present study, shown in Figure 4.

This research study has established positive and significant connections between aerobic fitness and cardiac autonomic modulation associated with HRV. The result of present study also showed that individuals with higher aerobic fitness levels tend to exhibit greater heart rate variability. VO2 max, a marker of cardiovascular endurance, appears to be linked with improved autonomic nervous system function, as reflected by higher HRV. This relationship indicates that individuals with better cardiovascular fitness may experience enhanced parasympathetic modulation, contributing to improved recovery and stress resilience. These findings emphasize the importance of aerobic fitness not only for physical performance but also for optimal autonomic regulation and overall cardiovascular health.

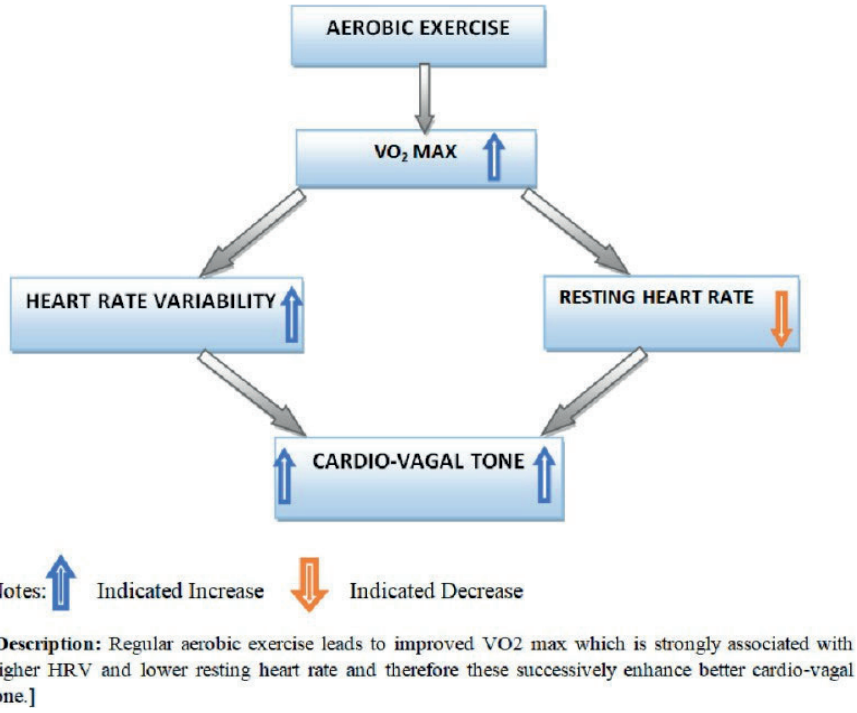


Figure 4. Mechanism of Cardio-vagal adaptation through Aerobic Exercise.

Conclusion

This study identified a significant correlation between VO_2 max and some of the selected HRV indices, supporting the notion that regular aerobic exercise or physical activity enhances cardio-vagal regulation and promotes a more balanced cardiac autonomic function. The current investigation focused only on male young adult participants who engaged in regular exercise and had a minimum training experience of four years. Considering the constraints of this study, involving elite athletes from various sports backgrounds, a larger sample size, and representation from both genders, along with long-term HRV monitoring, may yield improved outcomes and enhance understanding in future research.

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DIGITAL TOOLS TO SUPPORT PHYSICAL ACTIVITY AS AN ELEMENT OF SHAPING A HEALTHY LIFESTYLE FOR PROFESSIONALLY ACTIVE WOMEN

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Abstract The contemporary lifestyle of women working in offices leads to limited physical activity and sedentary behavior, which increases the risk of health problems. Digital tools, including training platforms, offer a potentially effective solution for supporting healthy lifestyle changes.

The aim of the study was to assess the impact of using a training platform on physical activity levels, selected eating habits, sleep quality, and lifestyle factors among adult women working in offices.

The study was longitudinal in nature and included professionally active adult women (n=158) employed in office positions in state-owned entities in the West Pomeranian Voivodeship. Data were collected at four time points: T0 (baseline), T3 (3 months), T6 (6 months), and T9 (9 months). A diagnostic survey approach was employed, utilizing proprietary questionnaires and the Athens Insomnia Scale. Analyses were performed using the Friedman test and post-hoc analyses with Bonferroni correction.

During the 9-month intervention, a significant increase in physical activity levels was observed, including an increase in the frequency and duration of activities of varying intensity. Some changes in dietary habits were also observed, including increased fluid and vegetable consumption. No changes in between-meal snacking were observed. Analysis of sleep parameters revealed a significant deterioration in subjective sleep quality throughout the intervention.

The training platform proved to be an effective tool for supporting increased physical activity in working women, but its impact on other lifestyle factors, particularly sleep quality, was limited.

Key words: physical activity, training platform, lifestyle, working women, digital intervention, sleep quality

Introduction

Modern lifestyles, particularly among office workers, are characterized by significant limitations in daily physical activity and prolonged sedentary time. These working conditions contribute to a number of adverse health consequences, including musculoskeletal disorders , circulatory disorders, decreased physical performance, and impaired mental well-being (Owen et al., 2010; Proper & van Mechelen, 2008). Numerous studies indicate that sedentary work is a significant risk factor for lifestyle diseases, regardless of leisure-time physical activity (Tremblay et al., 2017). This problem particularly affects professional women, who often fulfill numerous social and family roles in addition to their professional responsibilities, which may limit their ability to engage in regular physical activity (Biddle & Mutrie, 2008; Biernat & Tomaszewski, 2015). Research indicates that women working in sedentary positions are characterized by lower levels of physical activity and are more likely to report back and lower limb pain compared to women performing more dynamic work (Kruk, 2019). Physical activity is a key element of a healthy lifestyle and plays a significant role in preventing non-communicable diseases, maintaining functional fitness, and improving quality of life (WHO, 2020). Regular physical activity has a beneficial effect on both somatic and mental health, contributing to stress reduction, improved well-being, and increased energy levels (Dishman et al., 2013). From the perspective of physical culture sciences, activities aimed at developing lasting exercise habits tailored to individual abilities and environmental conditions are particularly important. In recent years, health promotion programs using digital tools, including training platforms and online applications, have become increasingly important. These solutions enable flexible adaptation of physical activity to user needs, increase the availability of health-promoting content, and promote systematic participation (Vandelanotte et al., 2016; Sallis et al., 2021). The literature emphasizes that interventions based on digital technologies can effectively support the motivation to engage in physical activity, especially in time-constrained adult groups (Michie et al., 2017). The growing body of recent evidence confirms the effectiveness of workplace and digitally delivered interventions aimed at reducing sedentary behavior and increasing physical activity among office workers (Rouyard et al., 2025; Bort-Roig et al., 2025). Contemporary studies also indicate that digital physical activity programs may significantly improve mental health outcomes among employees, including reductions in stress and depressive symptoms (Kanamori et al., 2025). Furthermore, the development of structured digital strategies tailored to occupational settings has been shown to enhance engagement and long-term adherence to movement behaviors (Parés-Salomón et al., 2025; Oppermann et al., 2025).

An example of such an initiative is the “New Year – Healthy Year” project, aimed at supporting the health of professionally active adult women working in public offices. A central element of the project was a dedicated training platform offering substantive and practical materials promoting a healthy lifestyle, with particular emphasis on regular physical activity adapted to the specific nature of sedentary work. The remote activities were complemented by open consultations led by a sports coach and a research team, as well as providing participants with basic exercise equipment enabling them to train at home. This intervention model aligns with current research trends in health promotion and women’s physical activity (Kruk, 2019; Biernat & Piątkowska, 2020).

The aim of the study was to assess the effectiveness of a dedicated training platform as a tool supporting the development of a healthy lifestyle for professionally active adult women working in offices. The following research questions were established: 1. Will the training platform contribute to an increase in the level of physical activity of the study women? 2. Will women using the training platform to increase their level of physical activity change their eating habits to health-promoting ones? 3. Will the training platform contribute to improved sleep quality among the

study participants? 4. Will using the training platform contribute to changes in selected lifestyle elements among the study participants? 5. Will the support provided to women in engaging in physical activity contribute to a reduction in overweight and obesity among the study participants? Based on the research questions formulated, the following research hypotheses were adopted: H1. The use of the training platform will contribute to a significant increase in the level of physical activity of the study women. H2. Women using the training platform to increase their level of physical activity will be more likely to adopt health-promoting changes in their eating habits. H3. Using the training platform will improve sleep quality among the study women. H4. Using the training platform will positively impact selected lifestyle elements of the study women, such as regular physical activity, health care, and free time management. H5. Supporting women in engaging in physical activity will contribute to reducing the incidence of overweight and obesity in the study group.

Material and methods

The research material consisted of data obtained from professionally active adult women working in government offices located in the West Pomeranian Voivodeship. Women qualified for the project were logged into a dedicated training platform, through which they could access prepared training materials. The content provided to participants was tailored to their physical activity levels, individual needs, and abilities, enabling a safe and gradual initiation of physical activity. The study was longitudinal in nature. Participants completed the research tools before beginning the exercise program and then after 3, 6, and 9 months of using the training platform. These were defined as time points: T0 (study start), T3 (3 months), T6 (6 months), and T9 (9 months). This allowed for the assessment of changes occurring in the study group throughout the project. Participants were enrolled in the "New Year – Healthy Year" project and voluntarily consented to participate in the study by submitting appropriate participation declarations. The study was conducted in accordance with the Declaration of Helsinki. The project received a positive opinion from the relevant bioethics committee, and all research procedures were conducted in accordance with applicable ethical standards, maintaining the anonymity and confidentiality of participant data. The study employed a diagnostic survey method, using a questionnaire as the research technique. The research tools assessed physical activity levels, selected lifestyle elements, and health factors relevant to physical activity. The study utilized a questionnaire assessing physical activity levels, a questionnaire assessing dietary habits, a questionnaire addressing selected lifestyle factors, and the Athens Insomnia Scale (AIS), which assesses sleep quality and the occurrence of insomnia symptoms. The collected data were statistically analyzed to assess changes occurring in the study group of women as a result of using the training platform. Statistical analyses were conducted using descriptive statistics, allowing for characterization of the study population and an assessment of the direction and scope of observed changes. Statistical inference allowed for the assessment of the relationship between use of the training platform and the level of physical activity, dietary habits, sleep quality, and selected lifestyle factors of the study women.

Group selection criteria

Inclusion criteria: female gender, age≥18 years, good health condition allowing for physical activity, access to mobile devices enabling the use of the training platform, informed consent to participate in the study.

Exclusion criteria: medical contraindications to physical activity, inability to use the platform regularly.

Statistical analysis

Statistical analysis was performed using Python 3.11 with the following libraries: pandas, numpy, scipy, statsmodels, matplotlib, and seaborn. For each variable, a repeated measures matrix was created containing only complete cases (participants with measurements at all four time points). Statistical tests were used: for continuous variables (physical activity), the Shapiro-Wilk test (α=0.05) was used to test for normality. Parametric ANOVA with repeated measures was used in the case of a normal distribution; otherwise, the nonparametric Friedman test was used. For ordinal variables (nutrition, sleep), the Friedman test was used. If a significant result was obtained in the main test ($p<0.05$), post-hoc analyses comparing all pairs of time points were performed: the Wilcoxon signed-rank test for nonparametric analyses, the paired-samples t test for parametric analyses, and Bonferroni correction to control for Type I error with multiple comparisons. Descriptive statistics for continuous variables were presented as mean ± standard deviation and median, and for ordinal variables as median with interquartile range (Q1-Q3). The level of statistical significance was set at α=0.05.

Results

A total of 158 women participated in the study at various stages. Due to missing measurements at some time points, the sample size varied across variables (from n=71 to n=134 for complete cases). Analysis of the 88 complete cases (Table 1) showed a statistically significant increase in the number of days of leisure-time walking during the 9-month intervention (Friedman test: χ^2=132.66, df=3, $p<0.001$).

Table 1. Number of days of leisure-time walking at specific time points

Point time	N	Mean	SD	Median	Min	Max
T0	88	3.26	2.53	3.00	0.00	7.00
T3	88	3.78	2.33	3.50	0.00	7.00
T6	88	4.34	2.26	4.00	0.00	7.00
T9	88	4.92	1.88	5.00	1.00	7.00

Source: own study based on the data received

Post-hoc analyses with Bonferroni correction showed significant differences between all pairs of measurements (all $p<0.001$), indicating a progressive increase in the number of walking days throughout the intervention period. The largest increase was observed between T0 and T9 (Δ=1.66 days/week, $p<0.001$).

The analysis of 88 complete cases (Table 2) showed a statistically significant increase in the number of days with intense physical activity (Friedman test: χ^2=172.59, df=3, $p<0.001$).

Table 2. Number of days of intense physical activity at specific time points

Point time	N	Mean	SD	Median	Min	Max
T0	88	0.82	1.18	0.00	0.00	5.00
T3	88	1.27	1.35	1.00	0.00	6.00
T6	88	1.95	1.41	2.00	0.00	7.00
T9	88	2.48	1.44	2.00	0.00	7.00

Source: own study based on the data received

All post-hoc comparisons were statistically significant (all p<0.001). Particularly impressive was the more than three-fold increase in the number of days with intense activity between T0 and T9 (Δ=1.66 days/week).

The analysis of 73 complete cases (Table 3) showed a statistically significant increase in time spent on intense activity (Friedman test: χ^2=164.49, df=3, p<0.001).

Table 3. Time of intense activity in an average day (minutes) at individual time points

Point time	N	Mean	SD	Median	Min	Max
T0	73	42.96	71.37	20.00	0.00	508.00
T3	73	49.21	71.08	27.00	0.00	512.00
T6	73	52.82	71.27	31.00	2.00	516.00
T9	73	57.18	71.64	33.00	3.00	521.00

Source: own study based on the data received

All pairwise comparisons were statistically significant (all p<0.001), with a total gain of 14.22 minutes between T0 and T9 (p<0.001).

The analysis of 88 complete cases (Table 4) showed a statistically significant increase in the number of days with moderate activity (Friedman test: χ^2=171.00, df=3, p<0.001).

Table 4. Number of days of moderate physical activity at individual time points

Point time	N	Mean	SD	Median	Min	Max
T0	88	0.78	1.41	0.00	0.00	7.00
T3	88	1.33	1.51	1.00	0.00	7.00
T6	88	1.89	1.49	2.00	0.00	7.00
T9	88	2.47	1.41	2.00	0.00	7.00

Source: own study based on the data received

All post-hoc comparisons showed significant differences (all p<0.001). The cumulative increase between T0 and T9 was 1.68 days/week, representing a more than 3-fold increase.

The analysis of 71 complete cases (Table 5) showed a statistically significant increase in time spent on moderate activity (Friedman test: χ^2=171.04, df=3, p<0.001).

Table 5. Moderate activity time in an average day (minutes) at individual time points

Point time	N	Mean	SD	Median	Min	Max
T0	71	39.38	72.26	15.00	0.00	508.00
T3	71	46.59	71.82	16.00	0.00	513.00
T6	71	50.83	71.66	25.00	2.00	513.00
T9	71	55.72	72.04	27.00	8.00	524.00

Source: own study based on the data received

All pairwise comparisons were statistically significant (all p<0.001). The total increment between T0 and T9 was 16.34 minutes (p<0.001).

The analysis of 83 complete cases (Table 6) showed a statistically significant increase in the amount of fluids consumed (Friedman test: χ^2=75.87, df=3, p<0.001).

Table 6. Number of fluids consumed during the day (rank) at individual time points

Point time	N	Median	Mean	Q1	Q3	Min	Max
T0	83	3.00	2.89	2.00	3.50	1.00	4.00
T3	83	3.00	2.95	2.00	4.00	1.00	4.00
T6	83	4.00	3.55	3.00	4.00	1.00	4.00
T9	83	4.00	3.57	3.00	4.00	1.00	4.00

Source: own study based on the data received

Post-hoc analyses showed a significant increase in fluid intake between T0 and T6 (p<0.001) and T0 and T9 (p<0.001). No significant difference was observed between T0 and T3 or between T6 and T9, suggesting that the main change occurred between months 3 and 6 of the intervention.

The analysis of 83 complete cases (Table 7) showed a statistically significant deterioration in the subjective assessment of dietary habits (Friedman test: χ^2=59.34, df=3, p<0.001). Higher rank values indicate a worse assessment (1=very good, 6=don't know/worst).

Table 7. Nutrition assessment (rank) at individual time points

Point time	N	Median	Mean	Q1	Q3	Min	Max
T0	83	3.00	2.54	2.00	3.00	1.00	4.00
T3	83	3.00	3.24	2.00	5.00	1.00	6.00
T6	83	4.00	3.77	2.00	5.00	1.00	6.00
T9	83	6.00	4.84	4.00	6.00	2.00	6.00

Source: own study based on the data received

All post-hoc comparisons except T3 vs. T6 were statistically significant, indicating a progressive deterioration in subjective nutrition assessment. Paradoxically, despite objective improvements (more vegetables, fluids), participants rated their nutrition increasingly worse, which may be due to increased nutritional awareness and a more critical approach to their own habits.

Analysis of 134 complete cases (Table 8) showed no changes in the extent of snacking between meals (Friedman test: χ^2=inf, p<0.001, but all post-hoc comparisons p=1.00).

Table 8. Snacking between meals (rank) at individual time points

Point time	N	Median	Mean	Q1	Q3	Min	Max
T0-T9	134	3.00	2.30	1.00	3.00	1.00	3.00

Source: own study based on the data received

The values remained identical at all time points, indicating no effect of the intervention on this aspect of eating habits.

The analysis of 83 complete cases (Table 9) showed a statistically significant increase in the number of vegetable servings consumed daily (Friedman test: $\chi^2=154.29$, df=3, $p<0.001$).

Table 9. Number of vegetable servings per day (rank) at individual time points

Point time	N	Median	Mean	Q1	Q3	Min	Max
T0	83	2.00	2.01	1.00	3.00	1.00	5.00
T3	83	2.00	2.12	1.00	3.00	1.00	5.00
T6	83	3.00	3.12	2.00	4.00	1.00	5.00
T9	83	4.00	3.73	3.00	5.00	2.00	5.00

Source: own study based on the data received

All post-hoc comparisons except T0 vs. T3 were statistically significant (all $p<0.001$). The mean number of vegetable servings increased from 2.01 to 3.73, representing an 85.6% increase and approaching the recommended 5 servings per day.

For all sleep variables, higher rank values indicate poorer sleep (e.g., 1=rapid sleep onset, 4=very delayed sleep onset). The observed increase in values therefore indicates worse sleep quality. Analysis of 80 complete cases (Table 10) revealed a statistically significant deterioration in the sleep onset parameter (Friedman test: $\chi^2=144.83$, df=3, $p<0.001$).

Table 10. Falling asleep after going to bed (rank) at individual time points

Point time	N	Median	Mean	Q1	Q3	Min	Max
T0	80	2.00	1.88	1.00	2.25	1.00	4.00
T3	80	2.00	2.05	1.00	3.00	1.00	4.00
T6	80	3.00	2.76	2.00	3.00	1.00	4.00
T9	80	3.50	3.40	3.00	4.00	2.00	4.00

Source: own study based on the data received

Post-hoc analyses showed a significant deterioration in sleep onset in all comparisons except T0 vs. T3. The mean rank increased from 1.88 to 3.40, indicating a shift from “fast sleep onset” towards “delayed sleep onset”.

The analysis of 80 complete cases (Table 11) showed a statistically significant increase in the number of nighttime awakenings (Friedman test: $\chi^2=147.51$, df=3, $p<0.001$).

Table 11. Nighttime wakings (rank) at specific time points

Point time	N	Median	Mean	Q1	Q3	Min	Max
T0	80	2.00	2.23	2.00	3.00	1.00	4.00
T3	80	3.00	2.43	2.00	3.00	1.00	4.00
T6	80	3.00	3.16	3.00	4.00	1.00	4.00
T9	80	4.00	3.70	3.00	4.00	2.00	4.00

Source: own study based on the data received

All post-hoc comparisons except T0 vs. T3 were statistically significant (p<0.001). The mean rank increased from 2.23 to 3.70, indicating a shift from "occasional" arousals toward "very frequent" arousals.

The analysis of 80 complete cases (Table 12) showed a statistically significant deterioration in the assessment of total sleep time (Friedman test: χ^2=150.87, df=3, p<0.001).

Table 12. Total sleep time (rank) at individual time points

Point time	N	Median	Mean	Q1	Q3	Min	Max
T0	80	2.00	2.00	2.00	2.00	1.00	4.00
T3	80	2.00	2.10	1.00	3.00	1.00	4.00
T6	80	3.00	2.95	2.00	4.00	1.00	4.00
T9	80	4.00	3.49	3.00	4.00	2.00	4.00

Source: own study based on the data received

All post-hoc comparisons except T0 vs. T3 were statistically significant. The mean rank increased from 2.00 to 3.49, representing a shift from rating sleep duration as "slightly insufficient" to "significantly insufficient".

The analysis of 80 complete cases (Table 13) showed a statistically significant deterioration in well-being the next day (Friedman test: χ^2=146.43, df=3, p<0.001).

Table 13. Well-being the next day (rank) at individual time points

Point time	N	Median	Mean	Q1	Q3	Min	Max
T0	80	2.00	1.64	1.00	2.00	1.00	3.00
T3	80	1.00	1.75	1.00	2.00	1.00	4.00
T6	80	3.00	2.51	1.75	3.00	1.00	4.00
T9	80	4.00	3.41	3.00	4.00	2.00	4.00

Source: own study based on the data received

All post-hoc comparisons except T0 vs. T3 were statistically significant. The mean rank increased from 1.64 to 3.41, representing a shift from "good" well-being to "significantly worse" well-being.

The analysis of 80 complete cases (Table 14) showed a statistically significant deterioration of mental and physical performance the next day (Friedman test: χ^2=165.76, df=3, p<0.001).

Table 14. Mental and physical performance on the next day (rank) at individual time points

Point time	N	Median	Mean	Q1	Q3	Min	Max
T0	80	2.00	1.65	1.00	2.00	1.00	3.00
T3	80	2.00	1.75	1.00	2.00	1.00	4.00
T6	80	2.50	2.51	2.00	3.00	1.00	4.00
T9	80	4.00	3.41	3.00	4.00	2.00	4.00

Source: own study based on the data received

All post-hoc comparisons except T0 vs. T3 were statistically significant. The mean rank increased from 1.65 to 3.41, representing a shift from “unimpaired performance” to “markedly impaired performance”.

The analysis of 80 complete cases (Table 15) showed a statistically significant increase in daytime sleepiness (Friedman test: χ^2=135.02, df=3, p<0.001).

Table 15. Daytime sleepiness (rank) at individual time points

Point time	N	Median	Mean	Q1	Q3	Min	Max
T0	80	2.00	2.18	2.00	3.00	1.00	4.00
T3	80	2.00	2.23	1.00	3.00	1.00	4.00
T6	80	3.00	3.05	2.00	4.00	1.00	4.00
T9	80	4.00	3.64	3.00	4.00	2.00	4.00

Source: own study based on the data received

All post-hoc comparisons except T0 vs. T3 were statistically significant. The mean rank increased from 2.18 to 3.64, representing a shift from “slight sleepiness” to “significant sleepiness” during the day.

Discussion

The aim of this study was to assess the effectiveness of using a digital training platform as a tool to support the development of a healthy lifestyle among professionally active women working in offices. The results indicate that participation in the long-term, nine-month intervention resulted in significant changes in physical activity levels and selected lifestyle elements; however, not all analyzed areas improved.

One of the most important study results was a significant increase in the level of physical activity among the women studied. An increase in the number of days spent walking during leisure time and an increase in the frequency and duration of moderate and vigorous activity were observed. These changes were progressive and sustained across subsequent measurement points, indicating the effectiveness of the tool in long-term support for physical activity. These results are consistent with the World Health Organization’s recommendations, which consider regular physical activity to be a key element in the prevention of lifestyle diseases and maintaining adult health (World Health Organization, 2020). The obtained results also correspond to the authors’ reports indicating that interventions using digital tools and online platforms can effectively increase physical activity levels among sedentary individuals (Vandelanotte et al., 2016; Müller et al., 2021). Flexible access to training content, the ability to individualize exercises and the lack of the need for physical presence in sports facilities promote systematicity and the consolidation of exercise habits, which is particularly important in the group of professionally active women.

Analysis of changes in dietary habits demonstrated the partial effectiveness of the intervention. The observed increase in fluid and vegetable consumption can be considered a result of increased health awareness among project participants. Similar relationships were observed in studies by other authors, who indicate that even indirect health education, implemented as part of physical activity programs, can lead to beneficial changes in dietary behaviors (Contento, 2016; Górnicka et al., 2019). The lack of changes in between-meal snacking, however, confirms that emotional eating habits are particularly difficult to modify and require long-term, targeted interventions. The deterioration in the subjective assessment of one’s own diet, despite objective, positive changes, is noteworthy. This phenomenon may result from increased nutritional knowledge and awareness, leading to a more critical self-

assessment. Similar observations have been described in studies on adult health education, which emphasize that increased health literacy does not always correlate with improved self-assessment of health-promoting behaviors (Nutbeam, 2008).

The most ambiguous study finding was a deterioration in sleep quality assessed using the Athens Insomnia Scale. These results contradict numerous literature reports indicating a beneficial effect of regular physical activity on sleep parameters (Kredlow et al., 2015; Yang et al., 2012). However, it can be assumed that the observed deterioration was related to the additional burden of combining work, family life, and regular participation in the project, as well as to possible evening exercise, which could disrupt circadian rhythms. It is also important to consider the longitudinal nature of the study, covering a nine-month period, which means participants were exposed to changing seasonal factors, occupational stress levels, and changes in mental strain. Research indicates that psychosocial and occupational factors play a significant role in shaping sleep quality in sedentary women (Åkerstedt et al., 2017).

In summary, the study results confirm the effectiveness of the training platform as a tool supporting increased physical activity levels and partial modification of dietary habits in women working in offices. At the same time, the results indicate the need to expand the intervention to include components related to sleep hygiene, regeneration, and stress management, which could increase the overall effectiveness of health-promoting programs implemented in the workplace.

Conclusions

1. The use of a training platform in a longitudinal study contributed to a significant increase in the level of physical activity of adult women performing office work, both in terms of the frequency of activity and its duration.
2. The greatest changes were recorded in relation to leisure-time walking and moderate and intense physical activity, which confirms the effectiveness of the training platform as a tool supporting regular exercise.
3. Using the training platform resulted in a partial modification of the eating habits of the surveyed women, manifested by an increase in the consumption of fluids and vegetables, with no changes in snacking between meals.
4. During the intervention, no improvement in the quality of sleep was observed in the studied women; on the contrary, a deterioration in the subjective assessment of sleep was noted, including difficulties in falling asleep, more frequent nocturnal awakenings and poorer daytime functioning.
5. The obtained results indicate that the training platform-based intervention effectively impacts selected lifestyle elements, primarily physical activity levels, but its impact on other health components is limited. The observed significant increase in physical activity levels and partial improvement in eating habits indicate a positive trend towards reducing the risk of overweight and obesity.
6. The training platform can be a useful tool for health-promoting support for working women, but the effectiveness of health effects requires a comprehensive approach that also covers other aspects of lifestyle.

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